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HUBERT WORK, SECRETARY
BUREAU OF MINES
H. FOSTER BAIN, DIRECTOR

UNDERGROUND VENTILATION AT BUTTE

BY

DANIEL HARRINGTON

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DEPARTMENT OF THE INTERIOR

HUBERT WORK, SECRETARY

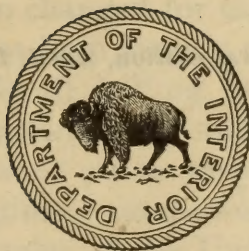
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FOREWORD.

This bulletin on underground ventilation in the copper and zinc mines at Butte, Mont., was written in 1919 from data collected by Mr. Harrington during 1916, 1917, and 1918, when he and Dr. Lanza of the United States Public Health Service were engaged on a study of miners' consumption in mines of the Butte district. Largely on account of conditions arising from the World War, publication was deferred until this date, and its issuance now is because of the fact that it contains much up-to-date general information on ventilation in metal mines, though many of the specific underground conditions described have since been materially changed.

The mines in the Butte district, with their hot rock, numerous veins, deep workings, and intensely concentrated activities, present to their operators many intricate problems requiring the utmost engineering skill. By no means the least of these problems is that of ventilation and this manuscript describes some of the numerous difficulties encountered in providing mine working places with safe, comfortable, and healthful air conditions.

Although the difficulties encountered are great, the mining companies have grappled with them and have made and are making wonderful progress in ventilation betterments, and the specific underground conditions described as existing in 1916, 1917, and 1918 have, in very large measure, been changed for the better in these ways:

1. The dust situation has been largely eliminated by the adoption of wet drills for practically all drilling, by the introduction of water lines for sprinkling to practically all working faces in many mines, and by increasing the flow of air to working places to remove dust as it is formed. Butte mining companies are in the front rank of those metal-mining companies of the United States that are trying to reduce the dust hazard.

2. Practically every mine in Butte has at least one man who devotes a large part of his time to ventilation, overseeing methods and devices designed to force moving currents of fresh air to the workers.

3. During the past few years the volumes of air delivered to individual Butte mines have been vastly increased, the increase varying from 50 per cent to several hundred per cent.

4. Nearly all Butte mines have sunk special shafts for ventilation, or have installed fans, or have otherwise made heavy financial expenditures for equipment or facilities to better ventilation.

5. Butte mining companies during the past five years have done much experimental work on ventilation equipment and devices—such as perfecting flexible tubes for air flow; changing small-sized commercial fans to meet underground requirements; devising and adopting methods for the smooth lining of air passages to decrease friction, and hence power consumption, in air delivery; also experimenting with various ventilating devices such as compressed-air injectors, compressed-air-driven underground local fans, etc.

6. The net result of these efforts is that average temperatures of working places have been reduced in some mines as much as 10° to 15° F.; lower workings with rock temperatures over 100° and previously almost unworkable have been converted into comfortable working places; and Butte mining companies now believe that in case their ore bodies reach to a depth of 5,000 feet or over, with rock temperatures 115° to 120° , they will be able to obtain for such deep workings an atmosphere which will allow of safe, comfortable, and efficient work.

As this report goes to press there is in progress a supplementary ventilation study in Butte mines; when that study is completed the Bureau of Mines expects to publish in more or less detail the improvements that have been effected and the means by which they have been brought about.

GEO. S. RICE,
Chief mining engineer.

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UNDERGROUND VENTILATION AT BUTTE.

By DANIEL HARRINGTON.

INTRODUCTION.

For several years the United States Bureau of Mines has been making a study of ventilation in metal mines, this study covering practically all the important mining districts of the country. One of the districts where a close and extended study was made was that of Butte, Mont., with its numerous interesting problems and conditions. In February, 1916, Daniel Harrington, mining engineer of the United States Bureau of Mines, was detailed to investigate the circumstances surrounding the death of 21 men in the fire at the Pennsylvania mine at Butte, and during that investigation he made underground visits to several of the large mines through the courtesy of the mine operators, and became much interested in the ventilation conditions. In May, 1916, Mr. Harrington was detailed to work in cooperation with Dr. A. J. Lanza of the United States Public Health Service in an investigation of the prevalence and causes of miners' consumption in the district. This work broadened so much that the investigation was not completed until late in 1918, the investigators making a detailed inspection of all working places in four large mines and a more or less extended examination of conditions in about 20 other mines.

Ventilation was recognized immediately as being an important factor in the health of miners, and from the outset of the investigation a large part of the work consisted in obtaining and compiling data relative to the flow of air, humidity, and temperature. The officials of the North Butte mine were engaged in making a study of ventilation problems before the coming of the investigators, so that opportunity was given to work with those officials for several months. Detailed data on air flow, temperatures, humidities, and an analyses had been obtained before the fire in the North Butte mine June 8, 1917, which resulted in the loss of 163 lives. Much information was obtained during the progress of the fire, and a detailed examination was conducted after the fire, hence an exceptional opportunity existed to study conditions relating to ventilation. This bulletin is a result of studies made from the data collected during the two and one-half

years of study and observation above outlined. Its publication has been delayed through lack of funds for printing. Other publications relative to metal mine ventilation in other parts of the United States are expected to follow.

ACKNOWLEDGMENTS.

Before the cooperative investigation, by the Bureau of Mines and the United States Public Health Service, of the health of miners at Butte began, letters were sent to the heads of Butte mining companies by Van. H. Manning, then director of the Bureau of Mines, outlining the purpose and scope of the proposed investigation and inviting the aid of the mining companies. Responses were prompt and cordial; throughout the two and one-half years consumed in the study practically all available facilities were afforded the investigators in their work, and access to underground workings was given at all times. The companies freely furnished underground guides to desired places, and at all times permitted complete freedom of movement, never hampering the opportunity for obtaining information from employees. The author expresses here his deep appreciation to the officials of the Butte mining companies and to their underground employees for the unfailing courtesy and good will accorded. The writer also acknowledges the cordial cooperation of Dr. A. J. Lanza, not only in underground investigations but in advice and helpful aid in formulating policies pertaining to mutual work. Many useful suggestions were made by G. S. Rice, chief mining engineer of the Bureau of Mines, regarding the data likely to be of value. Grateful acknowledgment is tendered the technical and analytical staff of the Bureau of Mines at Pittsburgh, Pa., for its efficient aid in making desired analyses.

MINING CONDITIONS IN THE BUTTE DISTRICT.

GENERAL STATEMENT.

Butte, situated on the Continental Divide, is probably the largest mining camp in the world, having a population of about 80,000 persons when mining operations reach capacity, as in 1916, 1917, and 1918; practically the entire population is dependent directly or indirectly on the mines, in which about 15,000 men are employed. Thus this one mining community, many mines of which lie within the city limits (see Pl. I), 95 per cent being included within a circle having a radius of $1\frac{1}{2}$ miles, employs as many metal miners as the States of Colorado, Utah, and New Mexico combined; half as many as the States of California, Nevada, and Arizona combined; and almost as many as the combined States of Nebraska, Kansas, Oklahoma, Texas, Missouri, Arkansas,



VIEW OF ANACONDA HILL, BUTTE, SHOWING SOME OF THE RICHEST AND MOST PRODUCTIVE MINES OF THE DISTRICT.

Louisiana, Mississippi, Alabama, Tennessee, Georgia, Florida, and North and South Carolina. From the opening of the Butte mines to the end of 1917 the metal production of the district has been about as follows:¹

Metal production of Butte mines.

	Quantity.	Value.
Copper -----pounds--	7, 150, 000, 000	\$1, 020, 000, 000
Zinc -----do----	610, 000, 000	65, 000, 000
Silver -----ounces--	310, 000, 000	220, 000, 000
Gold -----do----	1, 600, 000	32, 000, 000
Lead -----pounds--	40, 000, 000	2, 000, 000
		1, 339, 000, 000

The total value of the output to the end of 1918 was well over \$1,400,000,000. Ore reserves at present blocked out indicate that for many years an annual production of at least \$50,000,000 can be maintained, except when costs mount too high or selling prices drop too low.

ORES.

In general, the region around Butte is a granitic uplift through which run several series of veins that strike roughly east; the main producing veins, copper and zinc, strike nearly due east, roughly paralleling each other at distances up to several hundred feet apart; intersecting veins, many of which are good producers, that strike southeast, also roughly parallel each other at comparatively short intervals. As a whole, the veins dip south or southwest at angles ranging from 70° to 90°, though some veins dip as low as 45°; the dip of a few veins turns slightly to the northeast. In width the veins range from a few inches to 150 feet, the greater widths generally being above the 2,000-foot level; in one part of the district, however, practically all granite is mineralized below the 2,000-foot level because of the many intersecting veins. This intricate network is complicated further by offshoots from other veins by much faulting since the veins were formed.

The northern part of the district was a heavy producer of silver ores at the surface, with depth it shows large bodies of zinc sulphide, the Butte and Superior and Elm Orlu Mines now being important contributors to the world's supply of zinc. South of the zinc belt is the copper-producing territory extending under the main business part of Butte, as well as under Meaderville and East Butte. South and a little west of the copper-producing ground is a section, recently being developed, in which comparatively shallow deposits of zinc and manganese are assuming importance. About 2 miles

¹ Weed, W. H., Mines handbook and copper handbook, 1918.

west of the main copper-zinc-manganese mining district is a somewhat detached region with shallow mines, 1,000 feet or less in depth, that produce silver-lead ores.

The general country rock of the productive territory is a comparatively hard granite; the vein matter is either disintegrated broken granite, or possibly quartz fairly intimately intermixed with copper, zinc, or lead minerals; in many places, however, a vein has primary walls of granite with a quartz filling, and within the quartz a solid vein of copper sulphide, zinc sulphide, lead sulphide, or combinations of either one or more of these minerals with iron sulphide. Iron sulphide is found almost universally in the vein matter, and to a somewhat less extent scattered through the granite country rock. In some parts of the district the surface ores are oxidized, but in practically all the mines sulphides are found at depths of a few hundred feet.

The main productive section to date is included practically within a radius of $1\frac{1}{2}$ miles. This section has been so thoroughly worked and prospected underground that a person can go down almost any shaft there and come out of any other shaft, as nearly all of the mines are connected at various depths to adjoining mines.

MINING METHODS.

SHAFTS.

Practically all shafts in the Butte district are vertical, the original intent being to sink in the footwall and crosscut to the vein; however, because veins with a dip of about 70° parallel each other, frequently at intervals of a few hundred feet or less, the footwall of one vein is the hanging wall of another, and there are few shafts that do not intersect one or more veins. Consequently shaft movement is common and though expensive is unavoidable at many mines. In general, hoisting shafts have three or four compartments: Two about 4 feet 6 inches by 5 feet each are used for the main ore-hoisting skips or cages; a "chippy" compartment of equal dimensions with a cage operated by a separate hoist is used for handling men and material during the shift; the fourth compartment, usually smaller than the others, is used for pipe lines and power lines. Shaft timbers are usually 10 by 10 or 12 by 12 inches, the sets being about 5 feet apart, with appropriate lagging between the main timber and the walls. As reconstructed after the fire in 1917, the Granite Mountain shaft is lined with solid concrete from the 1,600 to the 3,000 level and is smooth-lined with "gunite" from the 1,600 level to the surface. Several shafts have been "gunited," and some are being smooth-lined with fireproof slabs between timber sets.

CROSSCUTS.

To a depth of about 1,500 feet it was customary to crosscut from the shaft to the vein at intervals of 100 feet vertically; below this depth, however, the general custom has been to have levels every 200 feet. Crosscuts and drifts are about 5 to 6 feet wide and 7 to 8 feet high, and are timbered only where necessary to support overlying material. When a vein is cut the drifting is generally done in the vein, though sometimes laterals are driven in the footwall at distances of 30 to 50 feet from the vein with crosscuts at intervals; or drifting may be done in the vein to be paralleled later by laterals in the footwall in the expectation that the laterals can be kept open readily, the maintenance of the drifts being difficult.

STOPING.

In practically all mines overhand stoping is used with some method of back filling. Usually square-set timbering is placed coincident with the removal of ore, followed by back filling between timbers, with waste or low-grade ore sorted from the stopes or trammed to convenient chutes from development crosscuts. Generally not more than two or three floors are left open, a "floor" being about 8 feet. Several modifications of this method are used, depending on the width of the vein, and the nature of the supporting walls and vein material.

Much experimenting has been done to limit the consumption of timber; and the most successful of these experiments has been the rill system, in the use of which little or no timber is used except in manways and chutes; back filling keeps pace with ore removal, and the mucking of ore or waste is at a minimum. If an ore deposit is only a few sets wide, a set being 5 feet 4 inches center to center, the entire width of the vein may be taken for considerable distances; where the width is 50 feet or over it is customary to attack the vein from footwall to hanging wall and in blocks 50, 75, or possibly 100 feet along the strike of the vein, leaving solid blocks on each side to be worked out later.

RAISES.

Generally before stoping begins raises are driven to the level above, either in the vein or partly in the footwall and partly in the vein or, occasionally, in the footwall. However, raising and stoping frequently are carried on together. Raises are spaced 35 to 50 feet apart along the vein and usually have two compartments each about 4 feet 6 inches square in the clear, timbered and lagged, one compartment being used as an ore chute and one compartment as the manway, carrying timber slide, and air pipe, together with ladders and land-

ing platforms, the latter being at intervals of not over 30 feet, under Montana law.

SORTING OF ORE.

Where the entire vein samples 3 per cent copper or more, little or no sorting is done, except, perhaps, to gob large boulders of waste. In some mines when a vein of high-grade ore a few inches to a foot or more wide is cut, and considerable waste from the walls must be shot down with the ore, sorting is done; in other mines the entire product is shipped as low-grade ore, leaving the "sorting" to be done by the mill or smelter. The ore shipped to the smelter has comparatively few lumps larger than 6 or 8 inches, and a considerable percentage of it is finer than 10 mesh; the ore shipped has a characteristic granite-gray color, about 95 per cent or more being granite or quartz.

DRILLING, SHOOTING, AND LOADING.

Wet drills are used considerably in drifting and crosscutting, much of this work being done by contract, generally by the linear foot with approximately \$1 per foot extra where timbering is required. For an ordinary drift or crosscut face in solid rock about 10 or 14 holes are drilled, the depth of hole being approximately 5 feet; holes are loaded with 7 to 10 or more sticks, $1\frac{1}{4}$ by 6 inches, of 40 per cent gelatine explosive, and a fuse is used with a No. 6 or No. 8 detonator. In stopes, wet drills are used but little, the usual drill being the dry stoper; some dry piston machines are used—mostly with the post, although some mines have the drills on tripods in the stopes. Stope holes are largely uppers, though some are inclined; the length of stope hole ranges from 2 to 3 or 7 feet or more, and the amount of explosive from 1 or 2 to 6 or 7 sticks, $1\frac{1}{4}$ by 6 inches, of 40 per cent gelatine or ammonia dynamite. The latter was widely used during the war, but was popular with neither the miner nor with the employer. Comparatively little contract work is done in stoping. In raises dry stopers are used almost exclusively and by far the greater number of the holes are drilled almost vertically upward; occasionally a dry piston machine is found working in a raise and more rarely a wet or Leyner drill. Holes are drilled 7 to 8 or more feet, and a round may require 30 or more holes. Much of the raise work is done by contract—usually by the cubic foot, though frequently by the linear foot.

In general, the pressure of the compressed air at working places is less than 70 pounds and frequently it is less than 40 pounds per square inch. The low pressures were common when the mines were working at capacity in 1916, 1917, and 1918.

Each level generally has a storage magazine for explosives with a separate place for detonators; in some mines, however, open boxes of

explosives are left at shaft stations, and in some mines detonators and explosives are stored at one point. The usual practice is to leave underground magazines absolutely open, the miner taking as much explosive as he wishes and at whatever time he pleases, without recording the amount taken nor the place used. Recently, however, some of the mines have adopted the practice of keeping magazines locked and of giving out explosives at a stated time by a man who exercises supervision over the amount to be used and keeps an accurate record of all explosives used.

The miner carries explosives and detonators from the magazine to the working face; some mines provide canvas bags, but others provide no containers for the explosive. Usually, the miner has powder in one hand or under his arm and detonators in his pocket or crimped to fuse in a coil around his hat. In placing and loading holes, the miner exercises his own judgment as to the location of the hole and the amount of explosive to be used; the general practice has been to do no tamping and to use no tamping material, except perhaps a few extra sticks of explosive. Recently, however, there has been a tendency to use foreign material, such as clay, for tamping. In the mines adopting this practice the saving of explosives has been as much as 20 to 25 per cent, especially when there is supervision of the supplying of explosives. In general, blasting is done at going off shift, with the understanding that a certain amount may be done during the lunch hour or even when the shift is working.

HAULAGE AND DRAINAGE.

In the newer work, electric locomotives taking a 250-volt current by trolley are generally used. Two or three mines use the storage battery locomotives to good advantage and there seems to be a tendency toward their adoption. In older sections, in those nearly worked out, or in those in which comparatively little work is done, mule haulage is found, as well as in new mines owned by small companies. A certain amount of hand tramming is also done for distances up to 1,000 feet; in some of the very poorly ventilated mines hand tramming is done for distances of 2,000 feet or more, as mules can not live in the places worked and the management seems to feel that the outlay for electric haulage would not be warranted.

In spite of the entire productive territory being badly cut and broken by fissures, veins, and faults, and many of the mine workings being more than 2,500 feet deep, comparatively little water enters the workings. Although about 40 mines are in operation, with open underground passages aggregating several hundred miles, the total water encountered probably amounts to less than 7,000 gallons per minute, more than half of which is pumped from the High Ore

and from the Leonard mines, which act as main gathering points and pumping stations for most of the big mines of Butte. The water pumped from the copper mines contains slightly less than one-tenth of 1 per cent of copper; it is run over scrap iron, and the copper in solution is precipitated, yielding a profit of several hundred thousand dollars annually. In the drifts underground the water is conducted in troughs, generally placed beneath the track; the water has to be kept from flowing over the track because as an acid copper solution it quickly destroys rails, spikes, and iron turn sheets.

MINE VENTILATION AT BUTTE.

USE OF NATURAL VENTILATION.

Until the Butte mines had gone below the 1,500-foot level, little or no attention was paid to ventilation, this being in accordance with usual metal-mining practice, though undoubtedly conditions existed that demanded the use of ventilating equipment. Natural ventilation caused some coursing of air, especially at certain seasons of the year. At depths below 1,500 feet, however, especially when conditions were complicated by mine fires, natural ventilation was seen to be insufficient and some mines installed electrically driven fans. The result is a decided improvement, compared to conditions before the installation of the fans or compared to neighboring mines that rely on natural ventilation.

USE OF FANS.

Several years ago the Anaconda Copper Mining Co. began to install electrically driven fans, and in 1918 had in operation approximately 150 fans, some acting as blowers, some as suction fans; several were placed on the surface, but most of them were underground. The total volume of air removed from the mines of that company amounted in 1919 to more than 1,300,000 cubic feet per minute. The actual total is difficult to obtain, as it involves measurements in about 30 upcast shafts, many of which are also used for hoisting and hence have a variable delivery of air. This quantity of air supplies about 9,000 men underground, or approximately 150 cubic feet per minute for each man; as only about 5,000 of these men are underground on the same shift, however, the real quantity per man underground per minute is 250 cubic feet or more.

The North Butte Mining Co., employing about 1,300 men underground, has two reversible electrically driven fans in fireproof houses on the surface at the collar of two upcast shafts; in addition, it has a third upcast shaft equipped with a fan that is used only for emergencies, the shaft ordinarily acting as a natural upcast. The downcast shaft for this mine is the main hoisting shaft; following the

fire of 1917, which burned out the shaft lining from the 1,600 to the 2,600 levels, it was relined with solid concrete from the 1,600 to the 3,000; and from the 1,600 level to the surface it was smooth lined with "gunite," giving a smooth-lined shaft from the surface to the 3,000 level. As a result, the delivery of air increased from slightly over 50,000 cubic feet per minute, before smooth lining, to over 80,000 cubic feet per minute after smooth lining, the same cross-sectional area, fan capacity, and power remaining practically unchanged.

The Butte & Superior Mining Co., which employs 1,300 men underground, the East Butte Mining Co., with 600 men underground, the Elm Orlu Mining Co., with 300 men underground, and the Davis-Daly Mining Co., with 200 men employed underground, depended wholly upon natural ventilation or compressed air or both until 1918, when the use of mechanically driven fans was begun.

REGULATION OF AIR CURRENT.

In general, the air distributes itself almost at will at various levels along the downcast shafts, although in some mines an attempt is made to regulate the flow by means of doors in the levels. Up to the end of 1920, however, comparatively little attempt had been made to conserve the supply of air and force it to the working faces in the blind ends of crosscuts, drifts, raises, and stopes; only infrequently were abandoned manways, stopes, and crosscuts sealed off, and as a consequence currents of air dissipated themselves through old workings from which they emerged on upper levels, the quantity in the general currents meanwhile being depleted until practically nothing was available for use at working faces.

Since 1917, however, some mines have tried systematic splitting of air currents and have had signal success. Also, much experimental work has been done, particularly in the North Butte mine, in the use of canvas pipe to transmit to blind end faces air forced by electrically driven fans capable of moving 1,500 to 10,000 cubic feet of air per minute. That this method is deemed a success may be inferred from the fact that early in 1918 the Anaconda Copper Mining Co. had in its Butte mines 129 small electrically driven fans with over 40,000 linear feet of canvas tubing, and orders had been placed for 300 more such fans and nearly 100,000 linear feet of canvas tubing.

In 1918, the Anaconda Copper Mining Co. assigned a man to study ventilation exclusively, with instructions to formulate and submit recommendations for improvements in ventilating its Butte mines. Following out the recommendations of this ventilation superintendent a campaign of betterment was undertaken which, according to local officials, would involve an expenditure of \$1,000,000, and which

Mr. John D. Ryan, president of the Anaconda Copper Mining Co., announced to the copper conference in Washington, D. C., in February, 1919, would amount to probably \$3,000,000. In this program every surface fan of the Anaconda Copper Mining Co. in Butte is to be replaced by one of approximately double capacity; the fans are to have a total capacity of about 3,000,000 cubic feet of air per minute with water gage up to 5 inches. These fans are made reversible and have fireproof housings. All upcast shafts in the company's mines at Butte are to be smooth lined, possibly with a plaster board of local invention and manufacture; all downcast shafts are to be "gunited" with sections every 100 feet of solid concrete back to the rock wall of the shaft for a height of about 10 feet to prevent the possible spread of fire. It is planned so to distribute air currents to the working faces that the compressed-air blowers for ventilation will be totally abandoned. It is expected that the saving in compressed air alone will repay the expenditure for the improvements mentioned.

In 1918, the East Butte Mining Co., the Elm Orlu Mining Co., and the Davis-Daily Mining Co. made their first installation of fans; the Elm Orlu Mining Co. assigned a man solely to ventilation work.

The depression in copper and zinc mining after the war may defer this unusual activity in the improvement of underground ventilation at Butte; but, as the future success in mining is dependent upon better working conditions underground, the work might well be hastened rather than postponed.

Investigation in the Butte mines revealed that most mines had done much good work to improve conditions governing the air supply, but that other mines at first were indifferent. The examinations dealt primarily with questions of health, nevertheless the writer, as a mining engineer, made his observations chiefly in the light of operating efficiency and costs, and relegated considerations of health and safety to the background.

About 25 mines were entered. In four of them detailed data were obtained in every underground place where men were working at the time of the investigation. Wet and dry bulb temperatures were taken at each place by two persons using sling psychrometers and checking readings. Rock and water temperatures were obtained where possible. Approximately 200 samples of air were collected in various places and under various conditions; these samples were analyzed at Pittsburgh, Pa., by chemists of the Bureau of Mines. Air velocity was measured where the movement was enough to use an anemometer; approximate velocities were obtained by other methods when an anemometer could not be used. The investigators' personal

feelings as to comfort or discomfort were recorded, with data on the number of men employed at the place, the nature of the work, and the dampness of the place. Record was made as to the use of compressed air in each place visited, and frequently the temperature and humidity of the compressed air at the end of the hose as well as at various distances from the end of the hose were recorded. A study was made as to the increase or decrease of temperature and humidity of the air in the downcast and upcast shafts, in drifts and cross-cuts, in manways, and stopes. Data were obtained on the distribution of air and the splitting of currents in certain mines, and on the flow of air in smooth-lined compared to unlined timbered shafts. Much time was given to studying the use of small fans and canvas tubing for getting air to working faces, the increase of temperature, decrease of humidity, influence on air temperature at the face, and the influence of water sprays on air temperature being noted. Mine fires were approached and studied, samples of gases from fires and from explosives collected and analyzed.

COAL-MINE AND METAL-MINE VENTILATION.

In general, the purpose of coal mine ventilation is to dilute and remove inflammable or asphyxiating gases and noxious fumes; to accomplish this it is necessary before starting a coal mine to plan a complete system of ventilation and this system must be flexible enough to accommodate itself to possible changes in working plans.

In nongaseous mines or sections of mines some laxity may be permitted in conveying the air supply to underground workings; but where these workings give off inflammable gas in sufficient volume to be designated as gaseous, any carelessness in maintaining an adequate air supply at working faces almost inevitably exacts an exorbitant price in lives and in pecuniary loss to the company.

In metal mining there is generally no such driving necessity for furnishing plenty of air as there is in coal mining, yet the economic loss in metal mines through the efficiency of workers being reduced by lack of ventilation, is undoubtedly much greater than the cost of ventilation in coal mines. Moreover, there are actually a greater number of reasons for adequate ventilation in metal mining than in coal mining. In metal mines, a supply of air is needed not only to remove noxious fumes after explosives, and frequently gases from the strata and from mine fires, but also to control humidity and to reduce temperature; in coal mines in the United States high temperatures are encountered rarely, and high air humidities are desirable.

FACTORS INFLUENCING THE TEMPERATURE OF MINE AIR.

TEMPERATURE OF OUTSIDE OR SURFACE AIR.

The temperature of the air outside a mine has much less effect on the temperature of the air in deep workings than on that in comparatively shallow ones, and much less effect in mines mechanically ventilated than those relying on natural ventilation. In midwinter when the outside temperatures in Butte are normally below 40° F. and on midsummer days when temperatures run above 80° F. (see

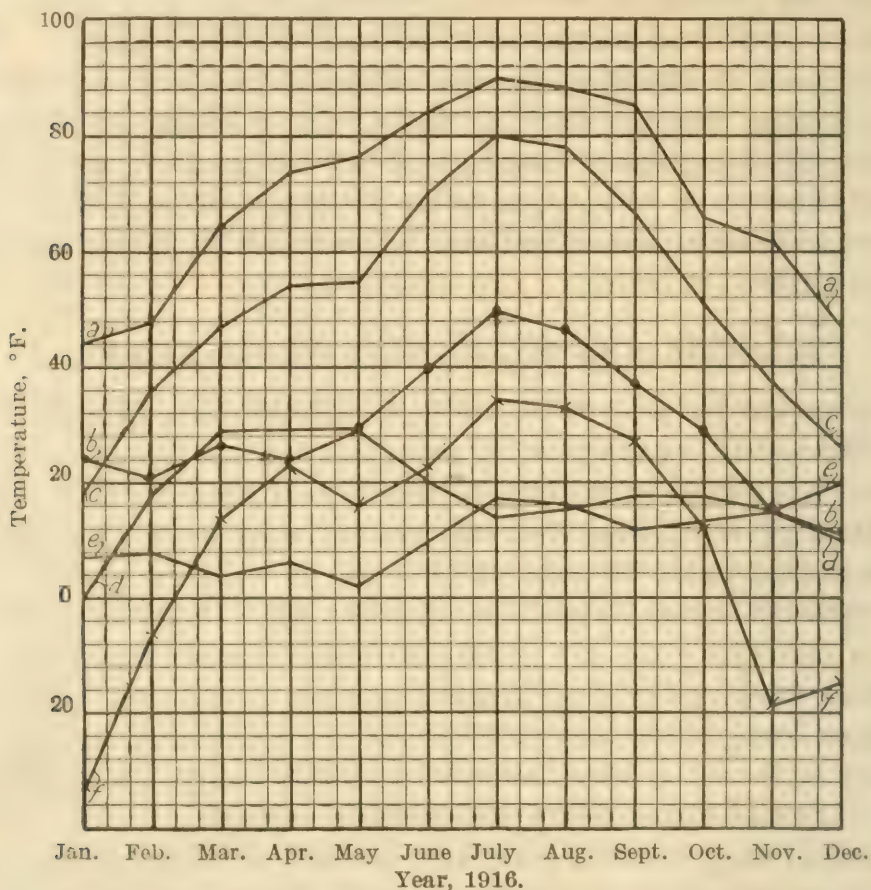


FIG. 1.—Weather data at Butte, by months, 1916: *a*, Maximum temperature; *b*, number of cloudy days; *c*, mean maximum temperature; *d*, number of clear days; *e*, mean minimum temperature; *f*, minimum temperature.

Figures 1, 2, and 3) in mines that rely on natural ventilation, and are 1,000 feet or less deep, hence have rock temperatures from 50° to 70° F., the ventilating pressure is considerable because of difference in temperature between surface air and underground air. On the other hand mines at 1,500 feet depth, having underground rock temperature and air temperature of 70° to 90° or over, have very little ventilating pressure in summer, though they have good pressure in winter, as in summer the daytime temperature outside and underground are about equal. (See Figures 1, 2, and 3, and Tables 1, 2, 3, and 4.)

TABLE 1.—*Temperatures at Butte for the years 1916, 1917, and 1918.*^a

Mean maximum temperatures, °F.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Average.
1916.....	18.9	36.7	47.5	54.2	54.3	65.9	79.6	77.6	67.0	51.0	37.8	26.4	51.4
1917.....	27.6	33.7	33.5	46.0	57.5	69.0	84.8	79.8	73.1	57.5	55.3	42.0	54.9
1918.....	32.3	35.3	49.4	50.2	59.2	79.1	79.9	75.3	70.0	59.0	38.9	34.7	55.3
Average.....	26.3	35.2	43.5	50.1	57.0	71.3	81.4	77.6	70.0	55.8	44.0	34.4	53.9

Mean maximum temperatures, °F.

1916.....	0.58	18.1	29.0	29.3	29.6	39.0	47.6	45.5	37.0	28.5	15.5	10.0	27.5
1917.....	10.9	15.0	12.7	26.4	36.0	40.8	52.3	47.4	43.4	32.4	27.0	24.9	30.8
1918.....	13.4	13.9	27.2	26.6	33.5	49.7	50.5	47.0	41.0	35.0	20.5	19.1	31.4
Average.....	8.3	15.7	23.0	27.4	33.0	43.2	50.1	46.6	40.5	32.0	21.0	18.0	29.9
Range of mean average temperatures..	18.0	19.5	20.5	22.7	24.0	28.1	31.3	31.0	29.5	23.8	23.0	16.4	24.0

^a Compiled from records of U. S. Weather Bureau.

TABLE 2.—*Maximum and minimum temperatures at Butte, °F.*^a

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Average.
1916.													
Maximum.....	44	48	65	74	76	84	90	88	85	66	62	47	68.6
Minimum.....	33	6	14	23	16	22	34	33	27	13	19	15	9.1
Range of temperature.....	77	54	51	51	60	62	56	55	58	53	81	62	59.5
1917.													
Maximum.....	47	46	53	63	79	86	94	86	85	76	69	66	70.8
Minimum.....	14	6	8	15	23	26	41	35	33	2	10	10	14.0
Range of temperature.....	61	52	61	48	56	60	53	51	52	74	59	56	56.8
1918.													
Maximum.....	56	53	63	65	79	91	91	89	85	85	59	55	72.6
Minimum.....	28	13	4	7	20	30	38	37	31	32	2	8	12.7
Range of temperature.....	84	66	59	58	59	61	53	52	54	53	57	63	59.9

^a Compiled from records of U. S. Weather Bureau.

TABLE 3.—*Clear and cloudy days at Butte.*^a

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Clear days.													
1916.....	7	8	4	5	2	10	17	16	12	13	15	11	121
1917.....	1	2	6	2	10	14	21	20	15	16	22	3	132
1918.....	8	9	13	5	6	14	11	10	11	12	14	14	127
Average.....	5½	6½	7½	4½	6	12½	16½	15½	12½	13½	17	9½	126½
Cloudy or partly cloudy days.													
1916.....	24	21	27	24	29	20	14	15	18	18	15	20	245
1917.....	30	26	25	28	21	16	10	11	15	15	8	28	233
1918.....	23	19	18	25	25	16	20	21	19	19	16	17	238
Average.....	25½	22	23½	25½	25	17½	14½	15½	17½	17½	13	21½	238½

^a Compiled from records of U. S. Weather Bureau.

TABLE 4.—*Precipitation at Butte.^a*

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1916.													
Snowy days.....	14	13	14	3	9	.....	.....	.....	.....	6	5	13	77
Rainy days.....	.....	.....	.....	1	10	16	6	6	5	4	.....	.....	48
No storm days.....	17	16	17	26	12	14	25	25	25	21	25	18	241
Snow, inches.....	13	6½	14	5½	7	.....	.....	.....	.....	(?)	12	21½	79½
Rain, inches.....	.....	.....	.....	0.88	1.97	2.56	1.48	0.39	2.00	0.96	.....	.....	10.24
1917.													
Snowy days.....	12	10	16	16	5	3	.....	.....	.....	7	2	10	81
Rainy days.....	.....	.....	.....	6	12	7	5	6	6	.....	.....	7	49
No storm days.....	19	18	15	8	14	20	26	25	24	24	28	14	235
Snow, inches.....	14	19	19	8	(?)	(?)	.....	(?)	.....	17	2	(?)	79
Rain, inches.....	.....	.....	.....	0.30	2.21	2.08	0.47	(?)	(?)	.....	.....	1.80	6.86
1918.													
Snowy days.....	18	7	8	13	3	1	.....	.....	.....	1	7	4	62
Rainy days.....	.....	.....	2	2	12	8	10	9	12	6	.....	.....	61
No storm days.....	13	21	21	15	16	21	21	22	18	24	23	27	212
Snow, inches.....	23½	10½	26½	(?)	(?)	(?)	.....	.....	.....	(?)	4½	.....	65
Rain, inches.....	.....	.....	0.50	1.52	0.64	1.09	2.54	1.11	1.88	1.45	.....	.....	10.73

¹ Compiled from records of U. S. Weather Bureau.

Mean average maximum temperature: June, July, Aug. (1916-1917-1918)=76.8° F. Dec., Jan., Feb. (1916-1917-1918)=32.0° F. Mar., Apr., May (1916-1917-1918)=50.2° F. Sept., Oct., Nov. (1916-1917-1918)=56.6° F.

In spring and fall as well as on many summer days in Butte when early morning and midday temperatures vary widely, from as low as 30° F. to as high as 85° F. on the same day, comparatively shallow mines depending on natural ventilation have air currents

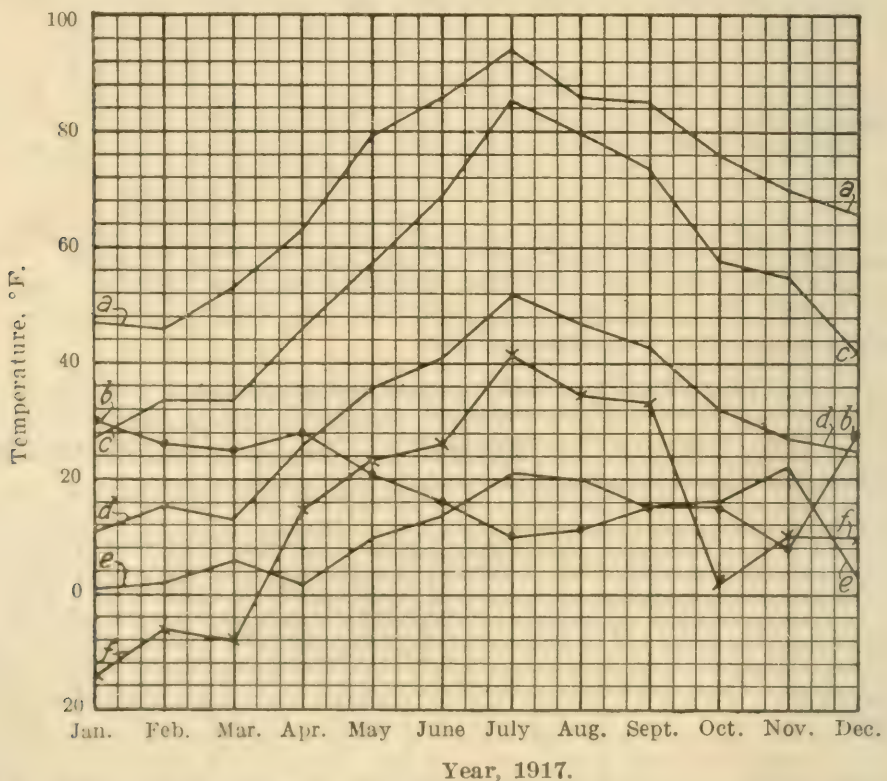


FIG. 2.—Weather data at Butte, by months, 1917: *a*, Maximum temperature; *b*, number of cloudy days; *c*, mean maximum temperature; *d*, mean minimum temperature; *e*, number of clear days; *f*, minimum temperature.

tending to flow, and in some instances actually flowing, in one direction during the night and early morning, and in the opposite direction during the midday and early evening, with two periods daily, pending the change, when there is little or no circulation of any kind. At those seasons the deeper mines have fairly good circulation except at midday when underground air currents are for several hours practically at a standstill. Where downcast shafts have much falling water or where there are underground fires heating the rock

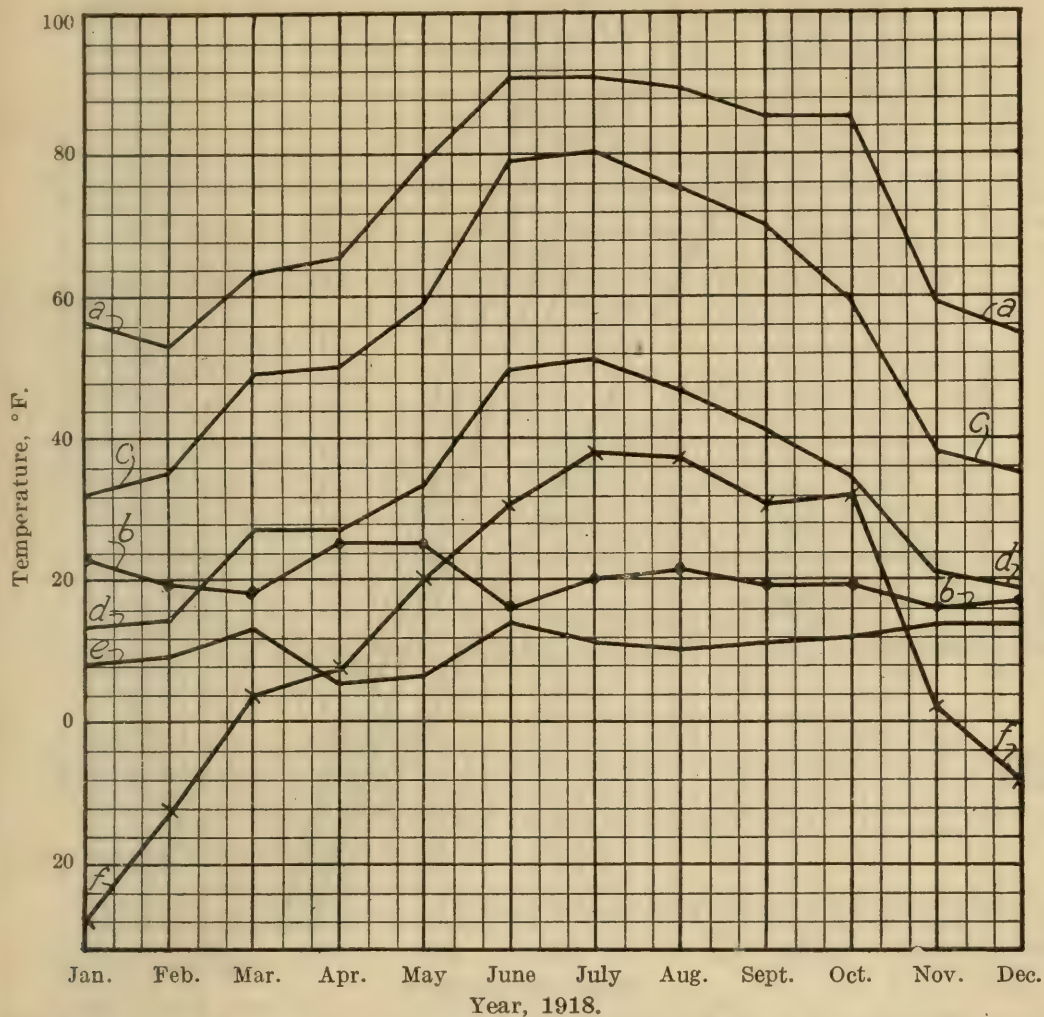


FIG. 3.—Weather data at Butte, by months, 1918: *a*, Maximum temperature; *b*, number of cloudy days; *c*, mean maximum temperature; *d*, mean minimum temperature; *e*, number of clear days; *f*, minimum temperature.

above 100° F., outside temperatures have little influence on the flow of underground air.

In deep mines mechanically ventilated, variations in the temperature of outside air may increase or decrease the power required to supply a constant quantity of air underground, but the influence of outside temperature changes on the temperature of underground air is not very noticeable.

Figure 4 shows that in a downcast shaft with an air velocity of 800 linear feet per minute, the winter temperature, dry bulb, at the

2,000-foot level varied less than 2° F. from the winter average of 52.7° F. for that point, though the surface air readings for the same days show a range of $24\frac{1}{2}^{\circ}$ F. Two spring and summer readings plotted show less than 1° variation at the 2,000-foot station from the summer average of 64.8° , though outside air temperatures on the same days varied 33° F., from 32 to 65° F. Notwithstanding the fact that variations in surface temperature were noticeable at sta-

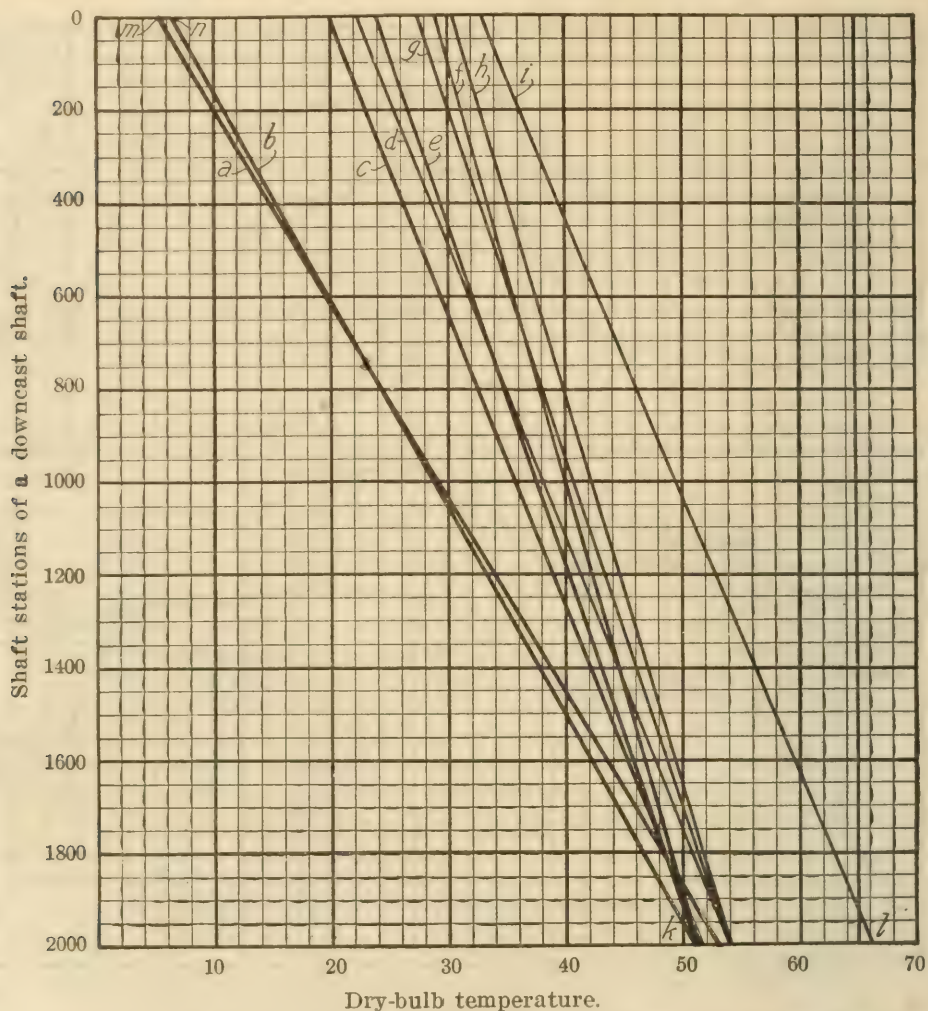


FIG. 4.—Constancy of air temperatures at the 2,000-foot station of a downcast shaft and the increase of the temperature of the intake air: *a*, 9.05 a. m., Dec. 7, 1916; *b*, 4.30 p. m., Nov. 13, 1916; *c*, Nov. 21, 1916; *d*, Nov. 24, 1916; *e*, Nov. 16, 1916; *f*, Nov. 15, 1916; *g*, Nov. 23, 1916; *h*, Nov. 17, 1916; *i*, Apr. 9, 1917; *j*, Sept. 22, 1916; *k*, dry-bulb temperature, winter; *l*, dry-bulb temperature, summer; *m*, previous night about 20° F. below zero; *n*, previous night about 25° F. below zero.

tions above the 2,000-foot level in this downcast shaft, which carried over 50,000 cubic feet of surface air per minute, practically no difference was discernible from day to day during winter in the air temperature, dry bulb, at stations below the 2,000, irrespective of whether the outside air temperature stood at zero or at 40° above zero. There was, however, a seasonal variation (Figs. 4 and 5), the summer average at points below the 2,000 being 5° to 10° F. higher than in winter, though the average maximum temperatures for three years at

the surface ranged from 32 to 76.8° F. (See Tables 1 and 2.) The day-to-day surface variations affect points below the 2,000 but slightly. The exception to this record occurs when surface temperatures are much in excess of 65° F., which is the average summer temperature of the 2,000-foot level in this shaft and essentially the

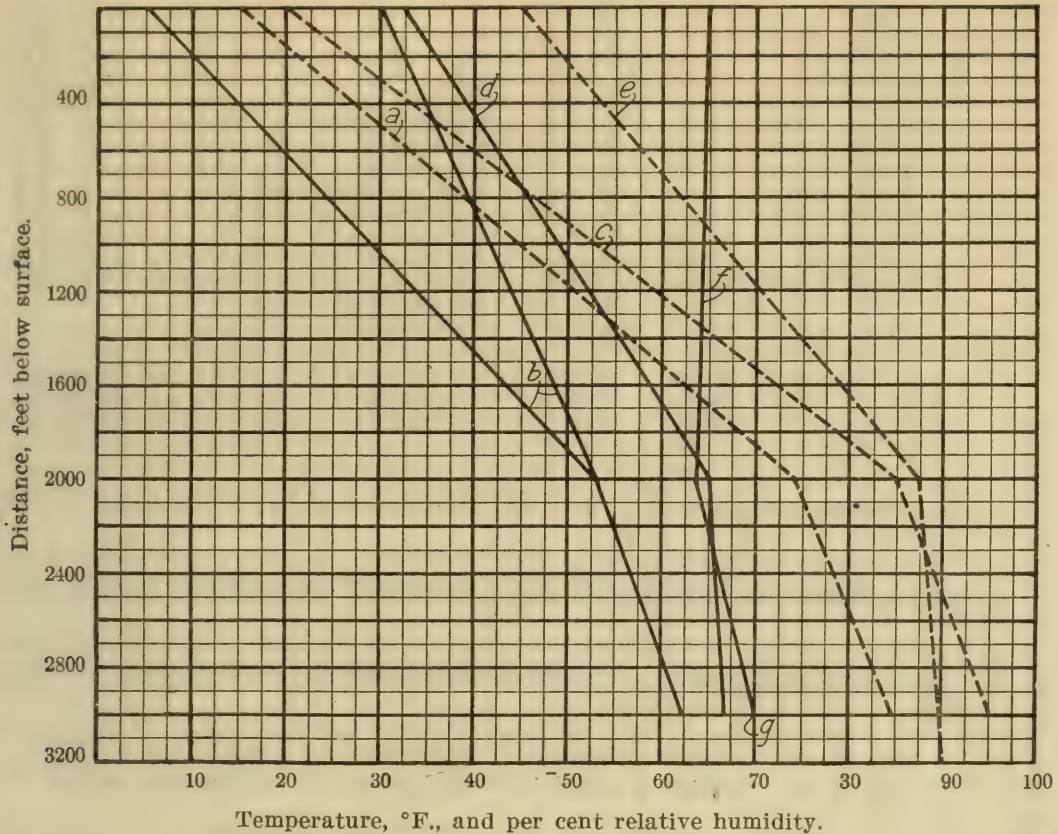


FIG. 5.—Seasonal variations of temperature and humidity in a downcast shaft: *a*, Humidity, winter; *b*, dry-bulb temperature in winter; *c*, humidity, summer; *d*, dry-bulb temperature, spring; *e*, humidity, spring; *f*, dry-bulb temperature, summer; *g*, rock temperature, 69.5° F. in 1917, 98° F. in 1914.

rock temperature at that point; the shaft air temperatures below the 2,000 are then raised to a certain extent above the average, but the very high surface temperatures, averaging 76.8° F. for June, July, and August as the mean average maximum for three years, are reduced materially toward the average readings above mentioned when the air travels down the shaft.

TABLE 5.—Readings along stations at a downcast shaft, mine A.

Date.	Time.	Surface.				Underground.						Remarks.
		Barom-eter.	Wet bulb.	Dry bulb.	Humid-ity.	Station.	Barom-eter.	Wet bulb.	Dry bulb.	Humid-ity.	Time.	
		Inches.	° F.	° F.	Per ct.		Inches.	° F.	° F.	Per ct.		
Jan. 5, 1917.	9.00 a. m.	23.62	29½	39½	100	400	.....	39½	39½	100	9.15 a. m.	In chippy compartment of shaft.
Jan. 3, 1917.	8.45 a. m.	23.48	23	37	92	700	.....	38	38	92	10.30 a. m.	Do.
Jan. 5, 1917.	9.00 a. m.	23.62	29½	39½	96	700	.....	40	40	96	9.40 a. m.	Do.
Nov. 9, 1916.	8.45 a. m.	.....	34	41	45	700	.....	43	46	78	8.55 a. m.	In main compartment of shaft.
								39.8	41.3	88.7		
Jan. 5, 1917.	9.00 a. m.	23.62	29½	37	88	800	24.07	40	41½	88	1.15 p. m.	
Nov. 10, 1916.	8.40 a. m.	23.77	8	35	83	800	24.29	35	37	83	8.50 a. m.	
Do.	4.10 p. m.	23.85	8½	35½	82	800	24.39	36.2	38.0	84.3	4.00 p. m.	
								41	41½	96		
Jan. 5, 1917.	4.10 p. m.	23.56	33	41½	85	1,000	24.19	41	43½	85	1.45 p. m.	In chippy compartment of shaft.
Do.	4.10 p. m.	23.56	33	53	87	1,200	24.56	53	54	87	2.15 p. m.	Do.
Mar. 28, 1917.	8.50 a. m.	.....	26	50½	90.5	1,500	.....	50½	52½	87	2.30 p. m.	Do.
								51.7	53.2	90.5	9.10 a. m.	In main compartment of shaft.
								99½	51	90		
Nov. 13, 1916.	1.00 p. m.	23.94	5	47	79	1,800	26.14	44	51	90	12.00 m.	Taken 5 feet from shaft on station.
Nov. 14, 1916.	1.00 p. m.	23.98	10½	55	83	1,800	25.18	55	55½	97	1.10 p. m.	Taken in chippy compartment.
Nov. 15, 1916.	1.00 p. m.	23.98	30	53	94	1,800	25.18	55	58	83	1.15 p. m.	Taken 5 feet from shaft.
Nov. 16, 1916.	1.05 p. m.	24.08	23	49½	80	1,800	25.18	61	62½	92	1.20 p. m.	Taken 20 feet from shaft.
							25.32	61	62½	92	1.10 p. m.	In main compartment of shaft.
							25.32	61	62½	92	1.15 p. m.	In chippy compartment of shaft.
							25.32	61	62½	92	1.20 p. m.	Taken 28 feet from shaft.
							.....	48.8	51.2	84.3		
Nov. 13, 1916.	4.10 p. m.	23.90	6½	48	80	2,000	25.31	48	51	80	4.00 p. m.	Taken on station; had been 25° below zero night before.
Nov. 15, 1916.	4.10 p. m.	24.05	28	48	80	2,000	25.38	48	51	80	4.00 p. m.	Taken on station.
Nov. 16, 1916.	1.05 p. m.	24.08	23	47½	78	2,000	25.44	47½	51	78	12.00 m.	In chippy compartment of shaft.
Nov. 17, 1916.	9.10 a. m.	24.03	29½	50½	82	2,000	25.44	51	54	82	12.10 a. m.	Taken 40 feet from shaft.
Nov. 21, 1916.	9.00 a. m.	23.79	19	47½	74	2,000	25.33	50½	54	79	9.15 a. m.	In chippy compartment of shaft.
Nov. 23, 1916.	9.10 a. m.	23.78	29½	51	82	2,000	25.17	47½	51½	82	9.15 a. m.	Do.
							25.13	51	54	82	9.30 a. m.	Do.
Nov. 24, 1916.	8.50 a. m.	23.84	21½	50	76	2,000	25.17	50	54	76	9.05 a. m.	Do
Nov. 28, 1916.	8.50 a. m.	23.63	21	52	82	2,000	24.96	52	55	82	9.00 a. m.	Do.
Dec. 7, 1916.	9.05 a. m.	23.82	5½	48½	73	2,000	25.14	48½	53	73	9.15 a. m.	In chippy compartment; previous night very cold.
Dec. 1, 1916.	8.50 a. m.	23.62	36	62½	87	2,000	24.86	62½	65	87	9.10 a. m.	
Apr. 9, 1917.	8.50 a. m.	.....	32	61	85	2,000	.....	61	64	85	9.15 a. m.	In chippy compartment of shaft.
Sept. 22, 1916.	12.00 m.	.....	47	51.5	79.8	2,000	.....	51.5	54.8	79.8	10.00 a. m.	In main compartment of shaft.
								51.7	53.2	90.5		

Nov. 17, 1916.	4.15 p.m.	23.89	33	38	58	2,200	.....	51	56	70	4.00 p.m.	In chippy compartment; velocity, 780 feet.
Nov. 21, 1916.	4.15 p.m.	23.79	.....	33	.....	2,200	25.39	51	55	76	4.05 p.m.	In chippy compartment.
Nov. 23, 1916.	4.20 p.m.	23.89	.....	30	.....	2,200	25.38	51½	57	69	4.10 p.m.	Do.
Nov. 24, 1916.	4.25 p.m.	23.82	.....	30	.....	2,200	25.32	51	55½	73	4.00 p.m.	Do.
Nov. 28, 1916.	4.15 p.m.	23.78	.....	24½	.....	2,200	25.21	53	57	77	12.00 m.	Do.
Dec. 1, 1916.	8.40 p.m.	23.51	32½	41	34	2,200	25.02	52½	58	70	9.20 a.m.	Do.
Apr. 10, 1917.	8.30 a.m.	.....	.....	32	.....	2,200	.....	62	65	87	9.30 a.m.	Do.
Nov. 28, 1916.	3.15 p.m.	23.78	.....	32.6	.....	2,400	.....	53.2	57.7	74.6	3.55 p.m.	Do.
Dec. 1, 1916.	4.40 p.m.	23.51	32½	24½	.....	2,400	25.12	55½	59½	78	3.30 p.m.	Do.
Dec. 4, 1916.	9.20 a.m.	23.62	.....	41	34	2,400	25.17	54	58	73	9.40 a.m.	Do.
Dec. 7, 1916.	9.05 p.m.	23.82	.....	5½	.....	2,400	25.49	51½	58	65	9.30 a.m.	In chippy compartment; preceding night very cold.
Dec. 11, 1916.	9.30 a.m.	23.76	.....	24	.....	2,400	25.49	51	56	70	9.35 a.m.	In chippy compartment.
Do.	.....	.....	.....	.....	.....	2,400	25.37	51½	57	68	9.45 a.m.	In main compartment.
Dec. 2, 1916.	9.15 a.m.	23.71	.....	23	.....	2,400	25.37	51	55	76	9.48 a.m.	In chippy compartment.
Mar. 13, 1917.	9.35 a.m.	.....	.....	16½	.....	2,400	25.29	53	58	73	9.40 a.m.	In chippy compartment.
Apr. 10, 1917.	8.30 a.m.	.....	.....	32	.....	2,400	.....	48½	53	72	.....	Taken 20 feet from shaft.
Dec. 4, 1916.	4.15 p.m.	23.64	.....	23.3	.....	2,600	.....	53.6	58.3	86	3.30 p.m.	.....
Dec. 7, 1916.	4.25 p.m.	23.88	.....	26	.....	2,600	25.38	55½	60	75	4.00 p.m.	All compartments of shaft.
Dec. 11, 1916.	9.30 a.m.	23.76	.....	15	.....	2,600	25.68	51½	58	65	4.10 p.m.	In chippy compartment.
Dec. 12, 1916.	9.25 a.m.	32.71	.....	24	.....	2,600	25.55	52	57½	69	10.45 a.m.	Do.
(?)	4.30 p.m.	23.85	.....	23	.....	2,600	25.46	52½	58	69	12.45 a.m.	Do.
Dec. 19, 1916.	4.10 p.m.	23.45	.....	25	.....	2,600	.....	53	57½	75	4.15 p.m.	In main compartment of shaft.
Mar. 27, 1917.	9.30 a.m.	.....	.....	16	.....	2,600	25.19	55	59	78	2.30 p.m.	Do.
Jan. 3, 1917...	8.45 a.m.	23.48	.....	26	.....	2,600	.....	51½	55½	76	9.45 a.m.	On station.
Dec. 11, 1916.	4.05 p.m.	23.82	.....	22.2	.....	2,800	.....	54.3	58.1	73.9	3.45 p.m.	In main compartment.
Dec. 14, 1916.	8.50 a.m.	23.81	.....	27½	.....	2,800	25.77	55½	60½	73	9.05 a.m.	Do.
Do.	4.30 a.m.	23.85	.....	13	.....	2,800	25.70	54	58	77	3.50 p.m.	Do.
Dec. 15, 1916.	8.50 a.m.	23.78	.....	25	.....	2,800	25.63	56½	60	81	9.05 a.m.	Do.
Dec. 19, 1916.	9.05 a.m.	23.44	.....	27	.....	2,800	25.28	55½	59½	78	9.15 a.m.	Do.
Jan. 4, 1917...	8.50 a.m.	23.62	.....	25½	.....	2,800	.....	57½	61	81	9.20 a.m.	Do.
Mar. 16, 1917.	11.50 a.m.	.....	.....	26	.....	2,800	.....	58	61	84	12.00 m.	Do.
Sept. 22, 1916.	12.05 m.	.....	.....	26	.....	2,800	.....	55½	59	81	.....	Do.
Dec. 4, 1916.	4.30 p.m.	23.85	47	24.3	.....	3,000	.....	56.1	59.9	79.3	11.00 a.m.	Present rock temperature on 3,000 station, 69½°.
Dec. 18, 1916.	9.30 a.m.	23.67	.....	65	20	3,000	25.88	69	70	95	3.40 p.m.	In main compartment.
Dec. 19, 1916.	4.10 p.m.	23.45	.....	25	.....	3,000	25.68	60	62	89	12.00 m.	Do.
Mar. 27, 1917.	9.30 a.m.	.....	.....	31	.....	3,000	.....	59½	62	87	1.10 p.m.	Do.
		.....	.....	16	.....	3,000	.....	61	62	94	10.05 a.m.	Do.
		.....	.....	26	.....	.....	.....	61.9	63.8	90	.....	.....

To recapitulate, surface air temperatures have an important bearing on underground air temperatures in shallow mines, or close to a downcast shaft or an intake air course in deep mines above the 2,000-foot level, particularly in those mines depending on natural ventilation. In deep mines, especially in those having mechanical ventilation, day to day or hour to hour variations in surface temperatures have very little influence on underground air temperatures

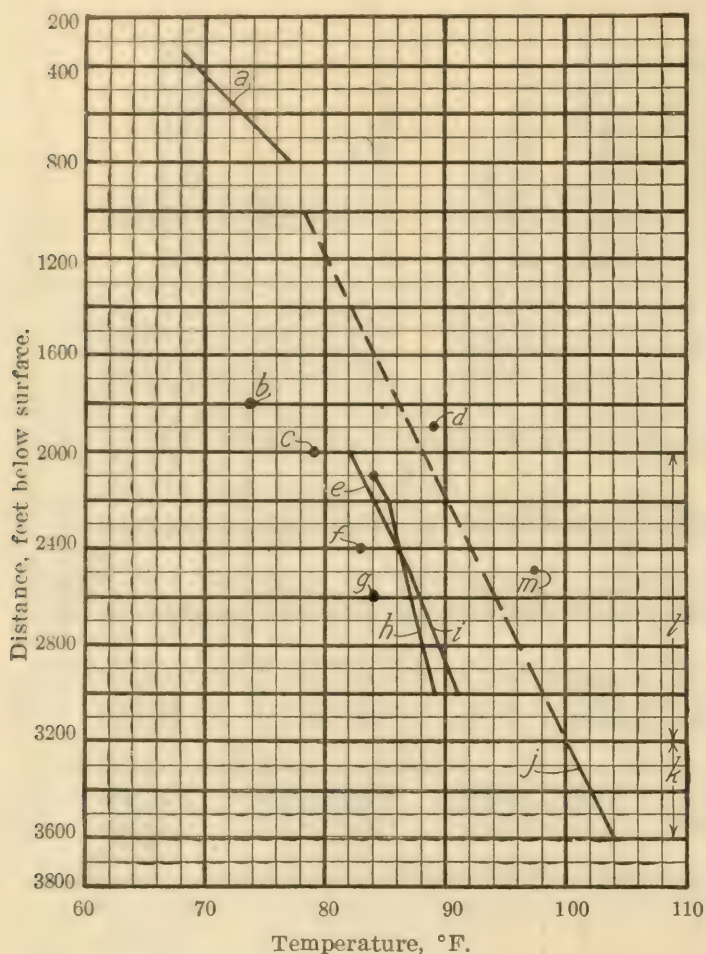


FIG. 6.—Rock temperatures at various depths in mines A and F, Butte, Mont.: *a*, "D" vein, rock temperature; *b*, zinc vein; *c*, "F" vein, rock temperature; *d*, "F" mine granite; *e*, granite; *f*, "C" vein, rock temperature; *g*, "B" vein, rock temperature; *h*, "A" vein, rock temperature; *i*, 0.9° F. increase to 100 feet depth; *j*, granite, 1° F. increase to 100 feet depth; *k*, horizon newly worked, *l*, horizon worked several years; *m*, "F" mine granite.

below the 2,000-foot level except in summer, when outside temperatures are greatly in excess of 65° F. Even in deep mines, however, a seasonal variation below the 2,000-foot level occurs, average summer shaft temperatures being 5° to 10° F. higher than the average winter readings. Table 5 gives day to day readings in a shaft and on the surface.

ROCK TEMPERATURES.

Rock temperatures undoubtedly affect air temperatures underground much more than do temperatures of outside air; on the other hand, air circulating underground has a well-defined effect on rock temperatures. Figure 6 shows

rock temperatures in one of the larger and deeper mines of the district, and Table 6 gives data as to rock and water temperatures in one large mine; the rock temperatures given are natural and not in any manner influenced by mine fires. There seems to be a difference in temperature between the solid granite country rock and the veins, the temperature of the granite generally being the higher. (See Figure 6, which was platted from readings taken in drill holes in advancing places.) The temperature of granite below the 3,000-foot

level increases 1° F. per each 100 feet of depth, the rock temperature being 100° F. on the 3,200-foot level. This gradient extended upward to the 3,000-foot level indicates a granite rock temperature for that level of 98° , but the actual rock temperature at the new face of a crosscut in granite was but 91° , a discrepancy of 7° F. This difference would seem to indicate a break in the heat gradient between the 3,000 and 3,200 foot levels. Probably, however, there is no break, the explanation being as follows:

Figure 6 shows a granite temperature-gradient of 0.9° F. per 100 feet of depth from the 2,000 to the 3,000 level, or essentially the same gradient as below the 3,000. The ground above the 3,000 had been worked for some years and presumably had been cooled by considerable volumes of cool air, approximately 70° F. on the 3,000, flowing continuously. The cooling effect was such that at the 3,000 station the granite temperature in an old hole about 4 feet deep was only $69\frac{1}{2}^{\circ}$ F. as against 91° F. in a hole in an advancing face in granite on the same level a few hundred feet distant. On the other hand, the granite temperatures on the 3,200, 3,400, and 3,600 were taken at advancing crosscut faces soon after the mine shaft had been sunk from the 3,000 to the 3,600 and the crosscutting had been started, hence were in virgin territory, ground that had been given practically no opportunity to cool. The temperatures below the 3,000 therefore seem to be natural, and those above the 3,000 to have been modified by cooling; the natural gradient of increase in both sections was essentially 1° F. per 100 feet of depth.

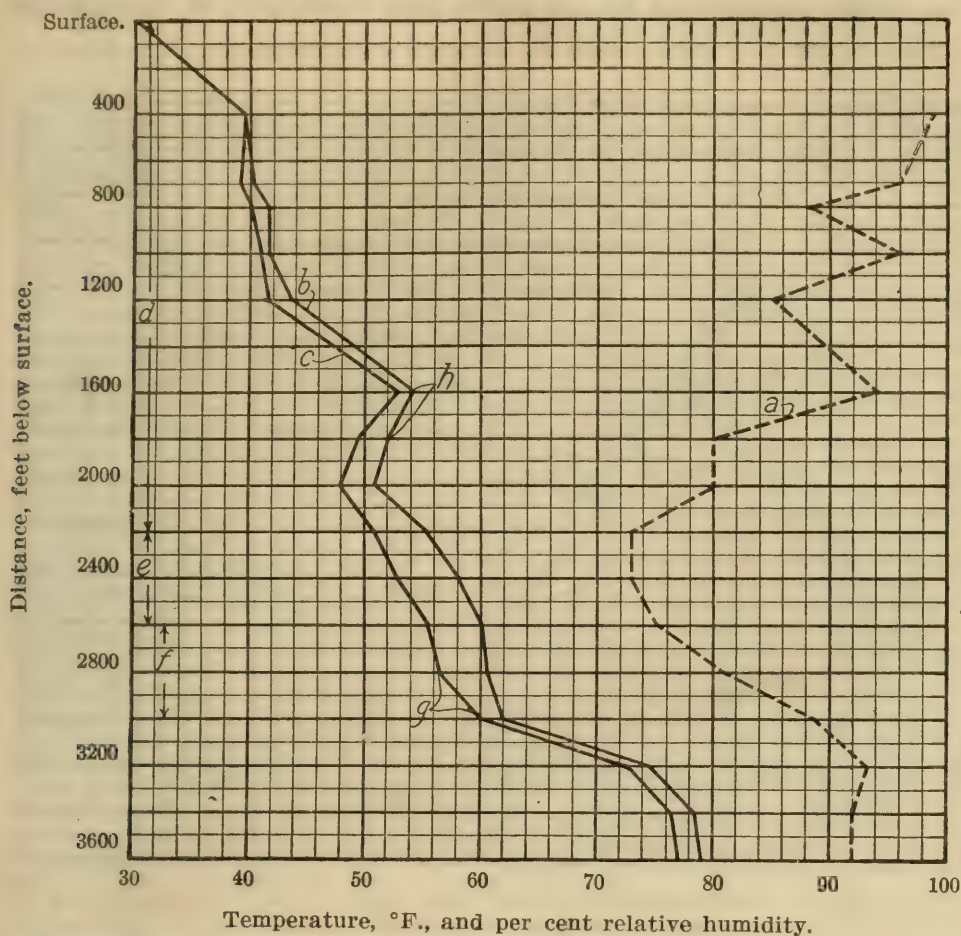
TABLE 6.—*Rock and water temperatures.*

Place.	Location.	Water temperature.	Rock temperature.	Remarks.
400.....	Near 453 chute.....	$67\frac{1}{2}$	.....	Water from back.
455 stope.....	Fifth floor.....	.....	68	In an upper hole in hard quartz carrying pyrite.
601 crosscut, fourth floor.	Near 727 chute.....	$52\frac{1}{2}$	.....	Water from back.
653 raise.....	Fourth floor.....	.....	61	In pile of wet loose material (old gob).
623 stope.....	First floor.....	.....	$62\frac{1}{2}$	In pile of damp loose material.
In 722 drift.....	About 300 feet from shaft.	$60\frac{1}{2}$	.....	Water from back.
In 700 crosscut.....	300 feet from shaft.....	55	.....	Considerable flow of water from fissure in solid rock below post.
853 stope.....	First floor.....	.....	77	In hole in old gob; hole drilled about 3 hours.
Do.....	First floor from above.	75	.....	From back, through old gob.
1,811 stope.....	Fourteenth floor near No. 11 chute.	77	.....	From back; vein has gangue of solid quartz.
1,800 drift at shaft..	At shaft.....	79	.....	Copious flow of water, "raising" in shaft.
2,003 drift.....	Breast 75 feet off 2,075 north.	.....	76	In hole drilled in breast 3 hours before with Leyner drill.
2,000 level.....	40 feet from shaft.....	$77\frac{1}{2}$	.....	Considerable fall of water down shaft.
75 feet west of 2,075 south; 2,002 drift.	Water from back.....	84	.....	Water through caved stopes from 1,800 to 2,000.
2,042 crosscut.....	In breast.....	.....	$81\frac{1}{2}$	In hole in granite breast drilled with Leyner.
2,083 drift.....	Breast; quartz vein.....	.....	79	In hole in quartz breast drilled with Leyner.
2,075 crosscut.....	350 feet from shaft.....	76	.....	Stream of water running on floor.
At shaft.....	At shaft.....	$78\frac{1}{2}$	.....	Streams of water falling down the shaft.

TABLE 6.—*Rock and water temperatures—Continued.*

Place.	Location.	Water temperature.	Rock temperature.	Remarks.
On 2,000 level.....	At shaft.....	78½	.....	Air temperature 78°-78½°, and at top of shaft (upcast air), 71½°-71¾° F.
2,254 stope.....	Twenty-second floor.....	86	.....	Taken in pile of loose quartz granite.
Do.....	Fifteenth floor.....	83½	.....	In an old hole in "sugar" quartz.
Do.....	do.....	86	.....	In a hole, in disintegrated granite, drilled approximately 3 hours.
2,217 stope.....	Fifth floor.....	84	.....	Upper hole in "sugar" quartz.
2,203 drift.....	Breast of drift.....	79	.....	Stagnant (copper) water on floor; drift not working; still air 78½°-79° at breast over water pool.
2,200 drift.....	25 feet north of bottom of No. 51 chute.	83	.....	Coming out of solid back; quartz carrying pyrite and bornite.
2,200 level.....	50 feet from shaft.....	71	.....	Considerable fall of water down shaft.
2,441 raise.....	Twenty-third floor.....	77½	.....	In loose rock; temperature of air 77°-79° F.
2,316 stope.....	Twenty-second floor.....	89	.....	In an upper hole in damp pyrite-chalcocite.
2,461 stope.....	Eighteenth floor.....	84	.....	In hole in granite, drilled 2 hours before with jack hammer.
2,419 stope.....	Seventeenth floor.....	86	.....	In an upper hole in damp decomposed chalcocite in breast.
2,420 raise.....	Thirteenth floor.....	85½	.....	Air in raise 83°-84° and at foot of raise 85°-86°
2,439 stope.....	Eleventh floor.....	83½	.....	In an upper hole in pyrite-bornite ore.
2,452 drift.....	100 feet from breast at intersection with drift.	80	.....	Water out of "back" from old stope.
Do.....	At breast.....	84	.....	Rock from hole in disintegrated granite.
2,401 crosscut.....	do.....	83	.....	In hole drilled 14 hours before.
2,475 crosscut, south.....	do.....	82	.....	In hole in dry hard granite.
2,625 stope.....	Twenty-second floor.....	82½	.....	In upper hole in disintegrated granite.
2,618 stope.....	About fourteenth floor.....	87½	.....	In short hole into granite (solid) footwall.
2,684 stope.....	Twelfth floor.....	87	.....	In upper hole in disintegrated granite.
2,664 stope.....	Ninth floor.....	84½	.....	In upper hole.
2,660 stope.....	do.....	82½	.....	In horizontal hole in dry granite footwall.
2,602 stope.....	Fifth floor.....	87	.....	In upper hole in pyrite.
2,682 stope.....	Third floor.....	89	.....	Air in stope, 86°-86½°.
2,602 stope.....	First floor.....	84	.....	In upper hole in hard quartz.
2,848 stope.....	Seventeenth floor.....	88	.....	Do.
2,850 raise.....	Fifth floor.....	87	.....	In loose ore.
2,816 stope.....	.....	87	.....	In upper hole in pyrite.
2,801 crosscut.....	900 feet from breast.....	88½	.....	Stagnant water on floor.
3,031 raise.....	Twenty-first floor.....	86	.....	In upper hole drilled 12 hours before.
3,006 stope.....	In crosscut on ninth floor about 20 feet into footwall.	86½	.....	In old hole in solid granite footwall.
3,017 stope.....	Fifth floor.....	87	.....	In pile of loose material.
3,019 stope.....	First floor.....	87½	.....	In upper hole in decomposed granite, ore bearing.
Do.....	do.....	87½	.....	In an upper hole in ore.
3,000 level.....	30 feet from chute.....	86	.....	Water green, yet comes out of solid material.
3,003 drift.....	Breast.....	86	.....	In a down hole drilled with Leyner.
Do.....	do.....	81½	.....	In pool on floor.
Do.....	10 feet from breast.....	76	.....	Drippers from vein (back).
Do.....	Breast.....	90½	.....	In hole in damp ore at breast; end of a hole blasted 2 hours before.
3,000 station.....	At station.....	69½	.....	In a hole 2½ feet into granite, drilled several months.
3,020 drift.....	Breast.....	91	.....	In old shattered hole about 12 inches deep in ore.
Do.....	400 feet from shaft.....	86	.....	From back (solid).
3,200 station.....	10 feet from shaft.....	81	.....	Upper hole in solid granite; starting to cut station; material had stood open for some months; air 73°-74½°.
3,275 south crosscut.....	50 feet from shaft.....	74	.....	Water "drippers" from top or back.
Do.....	50 feet from shaft, near breast.	100	.....	Hole in granite breast, recently drilled with Leyner; temperature of water used, 75°.
3,400 station.....	10 feet from shaft.....	87	.....	Upper hole in granite; material had stood open for months; air temperature 76°-78½°.
3,475 south crosscut.....	Breast 150 feet from shaft.	102	.....	Holes in granite breast, drilled 2 to 4 hours before with Leyner.
Do.....	Near breast.....	86	.....	Pool of water on floor, leakage from Leyner.
3,600 station.....	10 feet from shaft.....	95	.....	Upper hole in granite; material had stood open for months; air temperature 77°-79°.
3,675 north crosscut.....	75 feet from shaft, 35 feet from breast.	100	.....	Water "drippers" from back from solid material.
3,675 south crosscut.....	At breast 130 feet from shaft.	104	.....	In dry upper (60°) holes and water-filled cut holes, all drilled some hours before with Leyner.
3,700 station.....	In shaft.....	79	.....	Water comes from shaft.
Do.....	10 feet from shaft.....	82½	.....	Old pile of loose granite on floor.

Rock temperatures in veins are generally 2 to 3°, or even 5°, lower than in the granite country rock at the same level, and differ in different veins at the same level. One extensively worked fault-vein showing numerous slickensides as well as present-day ground movement has a temperature 3° F. higher than other veins at the same level and only a few hundred feet away. There also seems to be about



Temperature, °F., and per cent relative humidity.

FIG. 7.—Increase of temperature and humidity, by stations, in a downcast shaft on a day when the outside temperature was $29\frac{1}{2}^{\circ}$ F., dry bulb: *a*, Humidity; *b*, dry bulb; *c*, wet bulb; *d*, average velocity, 780 ft. a min.; *e*, average velocity, 450 ft. a min.; *f*, average velocity, 150 ft. a min.; *g*, present rock temperature $69\frac{1}{2}^{\circ}$ F., original rock temperature 98° F.; *h*, return air goes into shaft on 1,600 and 1,800 levels. Volume, over 50,000 cu. ft. a min. from surface to 2,400 level; average increase, wet bulb 400 to 3,000 ft., 0.79° F. per 100 ft.; average increase, dry bulb, 400 to 3,000 ft., 0.86° F. per 100 ft.; average increase dry bulb, at surface to 3,000 ft., 1.17° F. per 100 ft.; average decrease in humidity 400 to 2,200 ft., 1.5 per cent per 100 ft.; average increase in humidity, 2,400 to 3,000 ft., 2.67 per cent per 100 ft.

5° F. difference in rock temperature at the same level in zinc veins as compared with copper veins; both have a broken "sugar" quartz gangue carrying sulphides, but the zinc veins are the cooler. Natural water temperatures, as shown in Table 6, do not exceed rock temperatures at the same level as in many mines having high temperatures; in opening new ground, water temperatures are approximately equal to rock temperatures, but water temperatures fall more quickly after a lapse of time than rock temperatures, and it is not safe to assume that water temperature equals rock temperature.

Figure 7 gives wet bulb, dry bulb, and relative humidity of air at various points in a downcast shaft on a day when the outside temperature was $29\frac{1}{2}^{\circ}$ F. Figure 8 gives average readings at the same points in the same shaft taken over a six-months' period, but chiefly in cold weather, November to April. The increase in dry-bulb temperature, as illustrated in Figure 7, is 1.17° F. per 100 feet of shaft traversed from the surface to the 3,000-foot level, and is largely due to radiation from the rock, that is, to rock temperature.

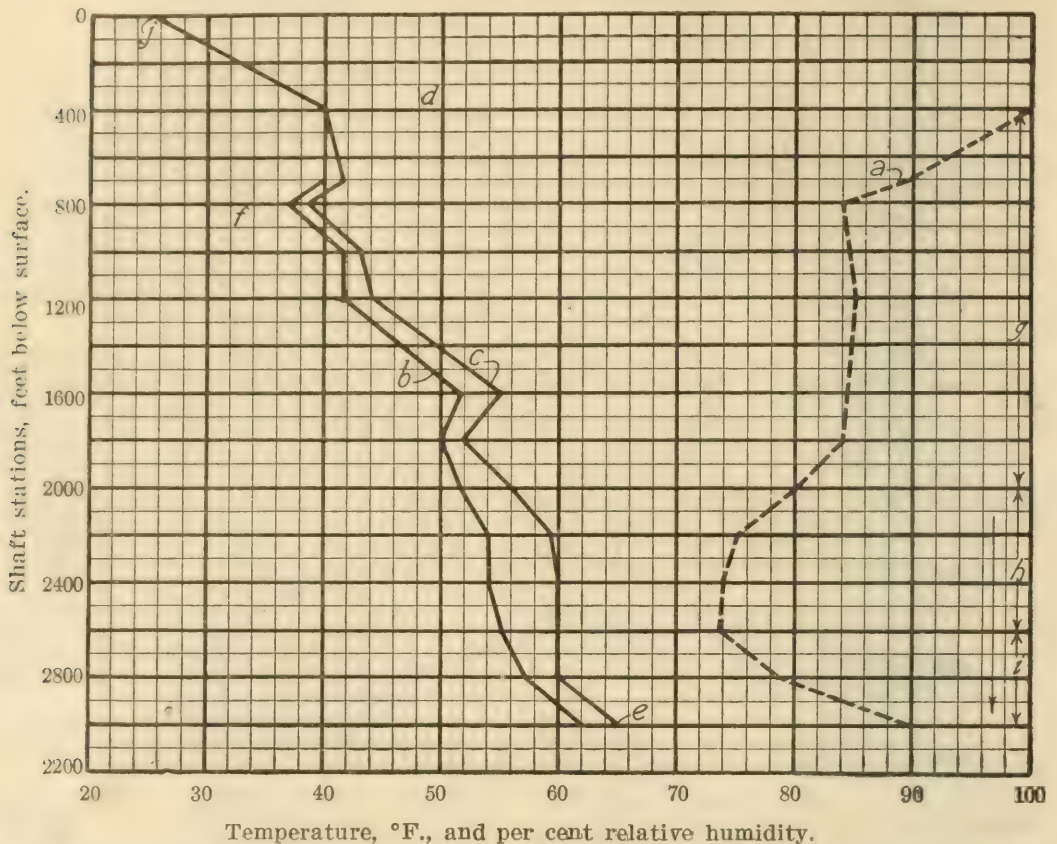


FIG. 8.—Average of readings of temperature and relative humidity in a downcast shaft, November, 1916, to April, 1917: *a*, Relative humidity; *b*, wet bulb; *c*, dry bulb; *d*, steam sprays from 1-inch pipe in shaft from surface to 700-ft. station; *e*, rock temperature, $69\frac{1}{2}^{\circ}$ F. in 1917, 98° F. in 1914; *f*, small amount of hot humid mine air enters downcast shaft; *g*, velocity, 780 ft. a min.; *h*, average velocity, 450 ft. a min.; *i*, average velocity, 150 ft. a min.; *j*, collar.

Figure 9 shows data taken in a downcast shaft in June, giving the average of 22 readings of surface temperature and humidity and the increase of relative humidity and temperature in the shaft, which was considered dry and carried about 30,000 cubic feet of air per minute.

In Figure 10 essentially the same increase, 1.17° per 100 feet, of dry-bulb temperature prevails in a crosscut for the first 800 feet of the flow of air (velocity, 150 feet per minute) and holds until the air temperature and rock temperature become practically equal, Figures 11 and 12 also show an increase in air temperature of practically 1° F. per 100 feet of crosscut traveled, the increase being

due almost wholly to rock temperature, as a velocity of less than 400 feet per minute would cause little increase of temperature through friction. Increases due to rock temperature are shown also in Figures 24 and 25 (pp. 42 and 43). For air velocities ordinarily prevailing in main air courses of metal mines the increase of air temperature through rock temperature is approximately 1° F. per 100 feet of travel until the air (dry bulb) temperature approaches the rock temperature.

At the blind end of crosscuts, drifts, and raises, and in stopes with little or no air circulation, air temperature rarely differs from rock temperature by more than 1° or 2° . More than half of the work-

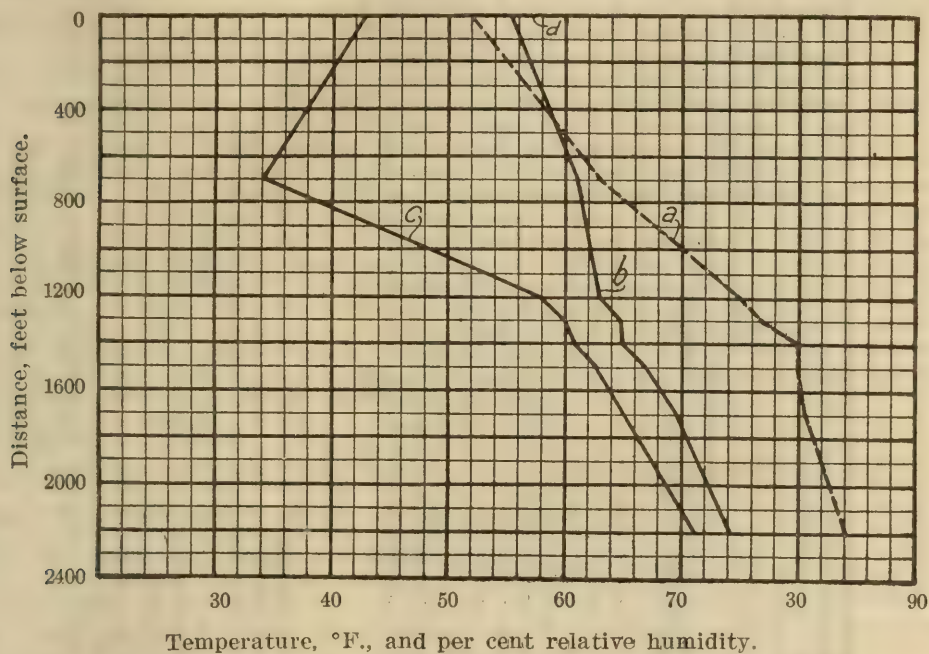


FIG. 9.—Temperature and humidity readings in a downcast shaft: *a*, Relative humidity; *b*, dry bulb; *c*, wet bulb; *d*, average of 22 surface readings taken June 12, 1916, to June 25, 1916, wet bulb 42.7° F., dry bulb 54.7° F., relative humidity 52 per cent. Increases per 100 ft. depth, surface to 2,200 ft.; relative humidity, 1.5 per cent; wet bulb, 0.8° F.; dry bulb, 1.3° F. Increases per 100 ft. depth, 1,200 to 2,200 ft.; relative humidity, 0.9 per cent; wet bulb, 1.3° F.; dry bulb, 1.1° F.

ing places in Butte mines have practically no air circulation, hence the great effect of rock temperature is evident, especially below the 2,000-foot level, where rock temperatures are well above 80° F. Moreover, probably half of all working places in Butte mines at present are below the 2,000-foot level. One big mine in which readings were taken at all working places had but 17 out of 158 working places above the 2,000 foot, another mine had 46 out of 88 places above that level.

Though rock temperatures have a decided influence on the temperature of underground air, the converse is also true, and air currents may either raise or lower rock temperature. Figure 6 (p. 20) shows that the temperature of the granite at the 3,000-foot station in

one of the deep mines of Butte is now only $69\frac{1}{2}^{\circ}$ F., but on the same level only a few hundred feet distant the granite temperature in an advancing crosscut face is 91° ; unquestionably the decrease of over 20° in the temperature of the rock on the 3,000-foot station is due to the fact that for several years large volumes of air at a velocity of 400 or more feet per minute and at a temperature less than 70°

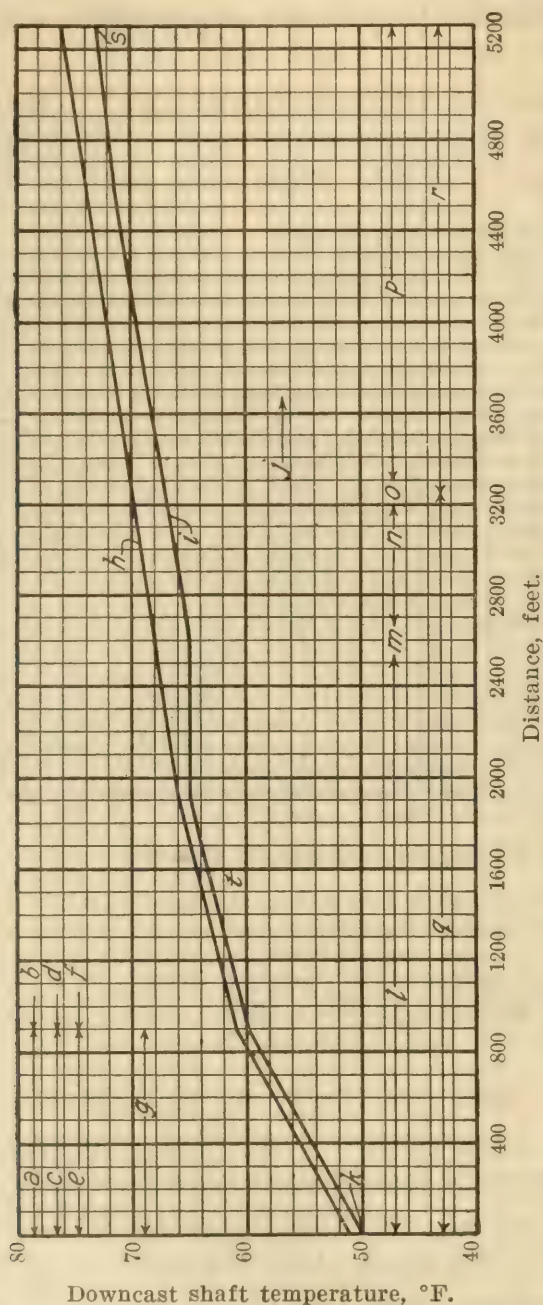


FIG. 10.—Increase of temperature of mine air in a crosscut, *a* to *f*, inclusive, friction and oxidation 900 to 5,200 ft. from shaft, increase per 100 ft.: *a*, Dry bulb, 1.17° F.; *b*, dry bulb, 0.33° F.; *c*, wet bulb, $1\frac{1}{4}^{\circ}$ F.; *d*, wet bulb, 0.33° F.; *e*, humidity, none; *f*, humidity, 0.11 per cent; *g*, rock temperature and friction; *h*, dry-bulb temperature; *i*, wet-bulb temperature; *j*, direction of air current; *k*, 1,200-ft. level, foot of downcast; *l*, wet untimbered unconnected crosscut, 1,200-ft. level; *m*, 100 ft. of timbered dry drift, 1,200-ft. level, above stopes to 1,300, 1,400, 1,500 ft. levels; *n*, 550 ft. partly timbered crosscut, 1,200-ft. level; *o*, 100 ft. timbered dry drift, 1,200-ft. level; *p*, fairly dry, partly timbered crosscut, 1,200-ft. level; *q*, velocity of air 150 ft. a min., volume, 6,930 cu. ft.; *r*, velocity of air 100 to 125 ft. a min., volume 5,700 to 4,000 cu. ft.; *s*, 1,200-ft. level, foot of 600-ft. raise; *t*, rock temperature.

have been abstracting heat from this rock. On the other hand, this rock now tends to cool the passing air on hot summer days when outside temperatures are between 80° and 90° F. (See Figs. 1, 2, and 3, and Table 1.)

Figure 12 presents data on the increase of air temperature in a crosscut off a shaft. The present rock temperature of this cross-

cut is 78° F., though its original temperature was approximately 94° F. For several years the crosscut carried about 14,000 cubic feet of air per minute at a velocity of about 400 feet per minute and an initial temperature of less than 60° F.

In a mine area the rock temperature was 152° F., but was reduced to 130° F. in less than a month by directing a stream of air at 90° F. into the place. Many similar instances may be cited, and no doubt exists that introduction of air currents can reduce greatly high rock temperatures; the rock helps to keep the air currents cool, as it does in many Butte mines every summer.

Air currents can cool rock and they can also raise its temperature. Figure 13 shows temperature readings in a crosscut over 2,000 feet long, with an original rock temperature of 72½° F.; after the crosscut had carried for 2½ years a current of about 19,000 cubic feet per minute, with initial temperature of 82° F., the rock temperature increased to 78° F. Figure 14 shows temperatures in a crosscut on the 800 level carrying return air from ground in which oxidation was going on. The original rock temperature of about 60° was raised to 77° F. by the passage of air for several years at a temperature of 86° and a velocity of 150 feet per minute, the air temperature being cooled in turn from 86° down to 78° F. in traveling about 3,300 feet.

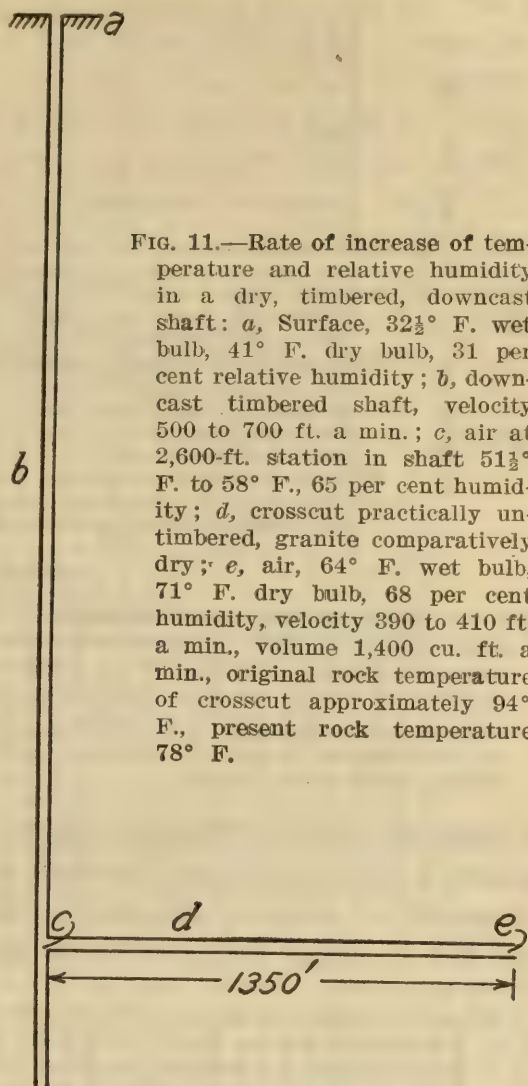


FIG. 11.—Rate of increase of temperature and relative humidity in a dry, timbered, downcast shaft: *a*, Surface, 32½° F. wet bulb, 41° F. dry bulb, 31 per cent relative humidity; *b*, downcast timbered shaft, velocity 500 to 700 ft. a min.; *c*, air at 2,600-ft. station in shaft 51½° F. to 58° F., 65 per cent humidity; *d*, crosscut practically untimbered, granite comparatively dry; *e*, air, 64° F. wet bulb, 71° F. dry bulb, 68 per cent humidity, velocity 390 to 410 ft. a min., volume 1,400 cu. ft. a min., original rock temperature of crosscut approximately 94° F., present rock temperature 78° F.

INCREASE OF TEMPERATURE.

	In 2,600 feet.	To 100 feet.
In shaft:		
Dry bulb-----	17° F.	0.66° F.
Wet bulb-----	19° F.	0.70° F.
Humidity (per cent).	31	1.2
	In 1,350 feet.	To 100 feet.
In crosscut:		
Dry bulb-----	13° F.	0.96° F.
Wet bulb-----	12½° F.	0.93° F.
Humidity (per cent).	3	0.22
	In 3,950 feet.	To 100 feet.
In crosscut and shaft:		
Dry bulb-----	30° F.	0.75° F.
Wet bulb-----	31½° F.	0.80° F.
Humidity (per cent).	34	0.86

Though in the Butte mines water does not have as much influence on temperatures as it has in some metal mines, such as those of the

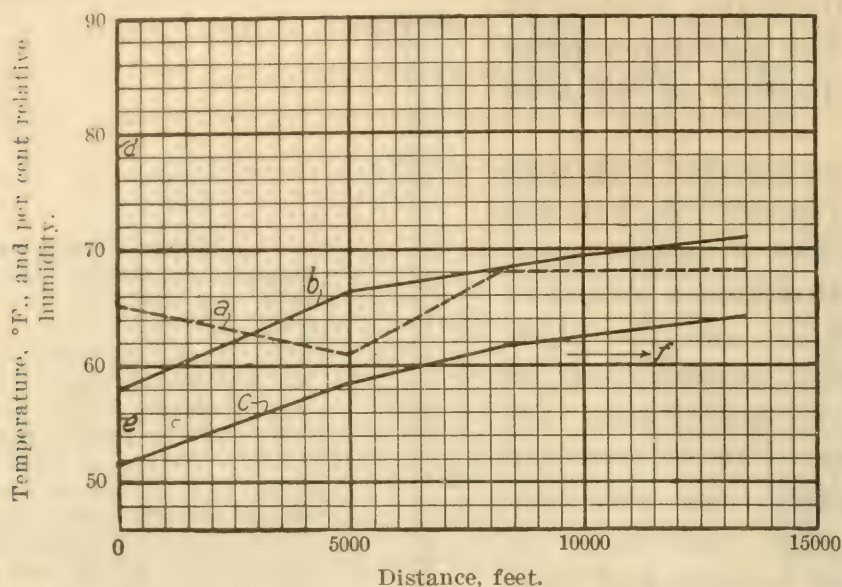


FIG. 12.—Rate of increase of temperature and relative humidity in a dry crosscut in mine A, 2,600-ft. level: *a*, Relative humidity; *b*, dry bulb; *c*, wet bulb; *d*, present rock temperature along crosscut 78° F., probable original temperature 94° F., 1,350 ft. dry untimbered granite crosscut with no connections hence no air contamination, practically no water and very little timber; *e*, wet and dry bulb and humidity of intake air at shaft station on 2,600-ft. level; *f*, direction of air, velocity 390 to 410 ft. a min., volume 1,400 cu. ft. a min.

Comstock Lode in Nevada, yet its effect is considerable. Figure 15 shows a downcast shaft having a fairly heavy flow of water, with the intensity of a heavy rainstorm, entering the shaft at a temperature of 48° F. about 100 feet below the surface; when the temperature

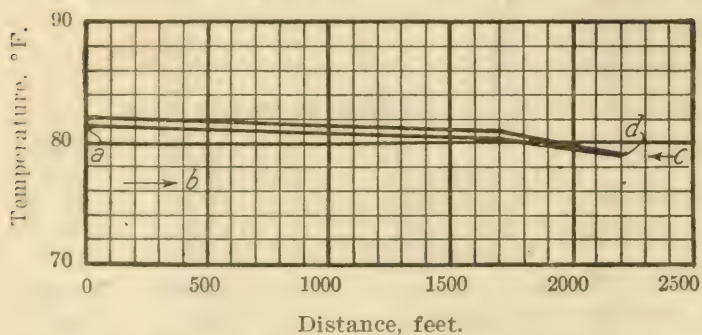


FIG. 13.—Rise of rock temperature in a return-air crosscut, mine A: *a*, Air coming up from raise, at top of raise from 2,200 ft. is 81.5° F. wet bulb, 83.5° F. dry bulb, at bottom is 83° F. wet bulb, 83.5° F. dry bulb, original rock temperature was 72.5° F., present rock temperature is 78° F., place opened 2½ years; *b*, decrease in temperature of return air, dry bulb is 2.5° F. in 2,200 ft. or 0.11° F. in 100 ft., wet bulb is 2° F. in 2,200 ft. or 0.10° F. in 100 ft.; *c*, direction of running water on floor; *d*, approximately 350 ft. from upcast shaft.

of the surface air stood at 74° F., at the 1,200-foot level the air temperature at the shaft was but 51° F. and the change in the water temperature was not enough to be detected with an ordinary thermometer; the volume of air was slightly above 13,000 cubic feet per minute.

Figure 16 shows the effect of water drippers in raising quickly the temperature of air after it leaves a canvas ventilating pipe; the temperature of the air leaving the canvas pipe,

25 feet from the face of the crosscut, at a velocity of nearly 4,000 feet per minute, is $77\frac{1}{2}^{\circ}$, but after going through 15 feet of a fairly copious dripping of water with a temperature of 90° , the air has a temperature of 88° F. at the face. Not all of this rapid increase of temperature is due to the warm water drippers, as the rock temperature at the face is 91° and there is always an injector effect by which considerable local air heated by the rock is drawn into the swiftly moving current. Figures 17 and 18 represent a lower level of a Butte mine, with rock temperature at the breast equal to 86° and water drippers with temperature of 76° , from the back at a point about 10 feet from the breast; a canvas pipe was delivering 1,500 cubic feet of air at a velocity of 4,200 linear feet per minute with issuing air temperature of 81° at a point 20 feet from the breast, the stream of air being directed toward the breast and through the

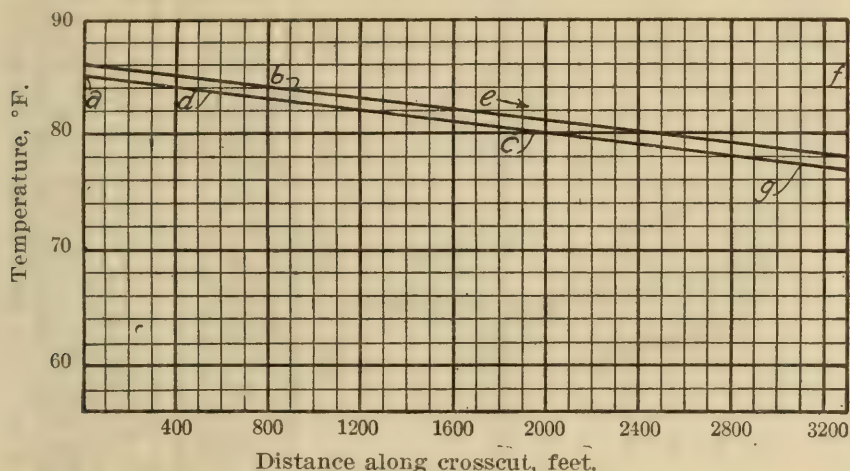


FIG. 14.—Decrease of temperature of return air on the 800-ft. level: *a*, Water from stopes 600 to 800 was 92° F., original rock temperature 60° F. including temperature due to oxidation, 32° F. at least; *b*, dry bulb; *c*, wet bulb; *d*, air velocity 125 to 150 ft. a min.; *e*, direction of air (return); *f*, upcast shaft; *g*, present rock temperature 200 ft. from shaft on 800-ft. level, approximate rock temperature originally 60° F.

water drippers. Temperature readings in the air current at the face showed 79° F. and 78° F. outside of the current. Here the air of the working place took the lower temperature of the water drippers rather than the temperature of the rock.

In the above examples of the influence of water on mine-air temperature the air velocities have been greater than those usual in working places, yet the effect even on swiftly moving air is marked; when velocities are 50 to 200 linear feet per minute or less, mine air quickly approximates the temperature of water drippers, especially if the latter extend over a fairly long distance, such as 200 or 300 feet. As most of the underground working faces at Butte have almost no movement of air, it is clear that the temperature in working places is essentially that of the water drippers or the surrounding rock. Many observations on the slowness of air movement at working places may

it; in one of the best ventilated mines of the district, 87 places out of 158 visited showed no air movement to the candle flame, and in 29 others air velocity was less than 100 linear feet per minute.

The effects of underground rock and water temperatures on underground air temperatures in Butte mines, then, are as follows: (1) The temperature increase in the country rock at Butte is about 1° F. for each 100 feet of depth, a rock temperature of 100° F. being reached at about the 3,000 or 3,200 foot level; (2) rock within veins is likely to have lower temperatures than country rock at the same level, though vein rock may have higher temperatures than country rock, especially if there is now much movement along the vein; (3) rock temperatures and air-current temperatures are inclined to

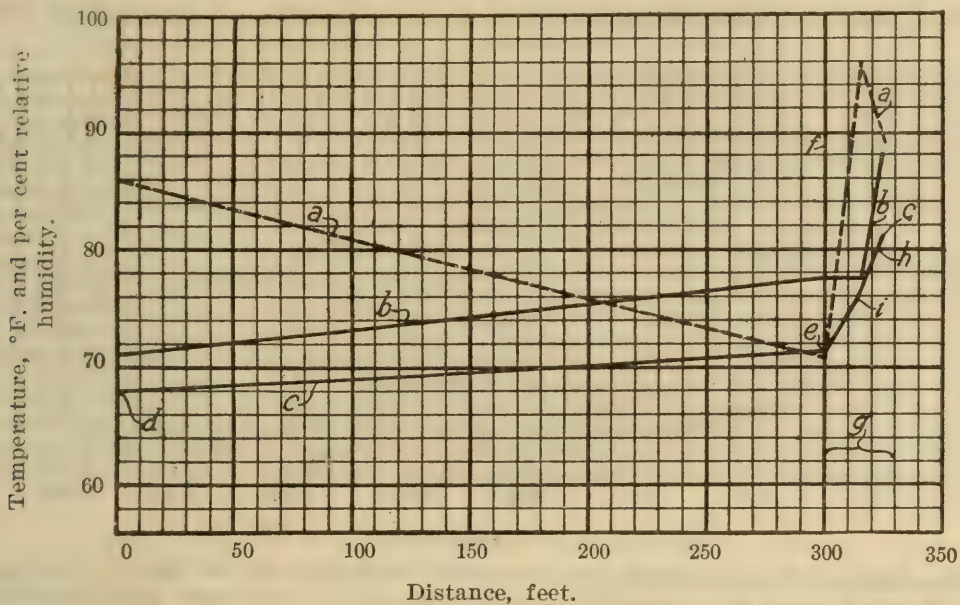


FIG. 16.—Increase of temperature and decrease of relative humidity of air flowing through canvas pipes: *a*, Relative humidity; *b*, dry bulb; *c*, wet bulb; *d*, water gage $4\frac{1}{2}$ in.; *e*, air velocity 4,800 ft. a min., water gage $1\frac{1}{2}$ in.; *f*, end of 10-inch canvas pipe; *g*, roof drippers; *h*, air readings at face of drift; *i*, air readings 10 ft. from face of drift; rock temperature at face, 91° F.

equalize, the air temperature increasing about 1° F. per 100 feet traveled, at velocities below 1,000 linear feet per minute, between rock walls of higher temperature until the temperatures approach equalization; on the other hand the coursing of considerable quantities of heated air tends to have the effect of raising the temperature of the adjacent cooler rock; (4) water temperatures in Butte mines are generally somewhat lower than those of rock, though the difference is usually only a few degrees. Water, when finely divided as a spray or drippers, has a decided tendency to change the surrounding air quickly to the water temperature, this tendency existing when the air has considerable velocity, being much stronger when the air is still or moves slowly. Moreover, comparatively small

quantities of water have a decided effect, a fact that may be utilized to advantage in devising a system to aid the cooling of underground air.

OXIDATION OF ORES AND TIMBER.

It is almost a certainty that much of the increase of rock, water, and air temperatures in Butte mines is due to oxidation of sulphide ores and of timber, but the exact measure or amount of that increase is not known. There are no authentic records of mine fires caused by the spontaneous heating of sulphide ores in Butte mines, though such fires have been reported from other mining regions.

In one Butte mine (Fig. 14) water at 92° F. comes out of a timbered back-filled stope that has been worked out and abandoned for several years; water temperatures at other parts of this mine from

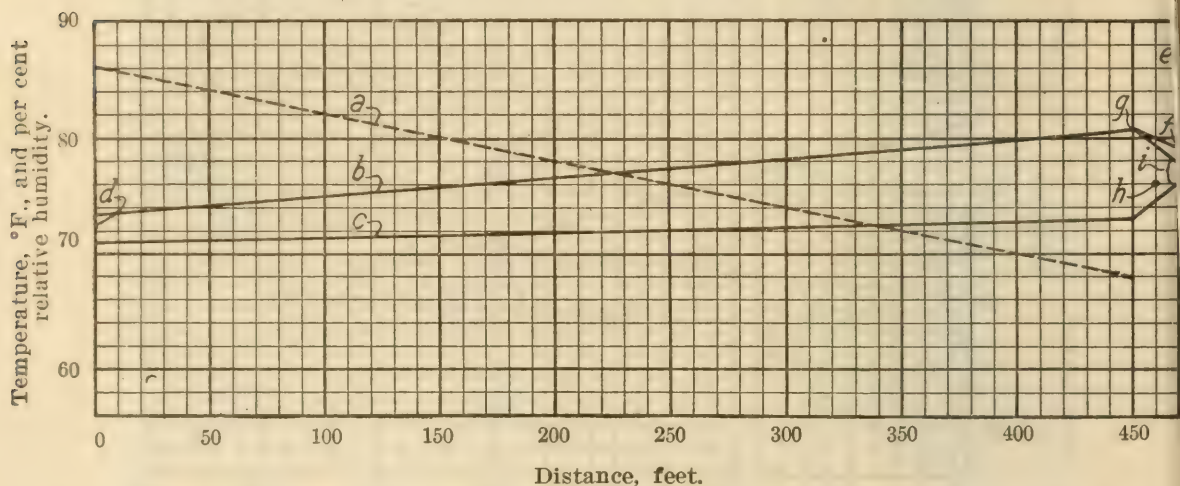


FIG. 17.—Increase of temperature and decrease of humidity of air flowing through 8-inch canvas pipe; effect of "drippers" on air temperature even with high surrounding rock temperature: *a*, Relative humidity; *b*, dry bulb; *c*, wet bulb; *d*, intake of air; *e*, rock temperature at breast 86° F.; *f*, breast; *g*, end of 10-inch canvas pipe, velocity 4,200 ft. a min.; *h*, water "drippers", mean air temperature at breast; *i*, in air current 76° F. wet bulb, 79° F. dry bulb; *j*, out of air current 76° F. wet bulb, 78° F. dry bulb.

solid territory and the same level are around 60° F., and the natural rock temperature, a few hundred feet away on same level, is only 60° F. As this mine has never had any fires, the increase of water temperature from 60° to 92° must be due to oxidation, either of timber or of finely divided sulphides in the back filling material, or both. Figure 19 (p. 34) shows a decided increase in temperature. Air goes from the 1,200 level at 76°, dry bulb, then up a raise to the 800, and a short distance through some stopes close to the heating area mentioned; it leaves these stopes at 86° F., though the normal rock temperature in the heating area should be, and probably once was, less than 60° F.

Figures 19 and 20 (pp. 34 and 35) indicate an increase of underground air temperature through friction or oxidation, or possibly both. The

air in the 1,200-foot level at the downcast shaft had a dry-bulb temperature of 51° , and after flowing 900 feet at a velocity of about 200 linear feet per minute in the damp, untimbered 1,200-foot crosscut, the air was $10\frac{1}{2}^{\circ}$ F. warmer, its temperature being $61\frac{1}{2}^{\circ}$ F., the natural rock temperature for that level. Beyond this point (900 feet from the downcast shaft) the air continued to flow at a velocity of about 200 feet per minute through a damp crosscut, water on the floor having a temperature of 60° to $61\frac{1}{2}^{\circ}$ F., and at a point slightly more than 5,300 from the downcast shaft had a temperature of 76° , notwithstanding the fact that the rock and floor water (or floor) had temperatures less than 62° . This figure shows the air became $14\frac{1}{2}^{\circ}$ F. warmer in traveling about 4,400 feet through a damp partly tim-

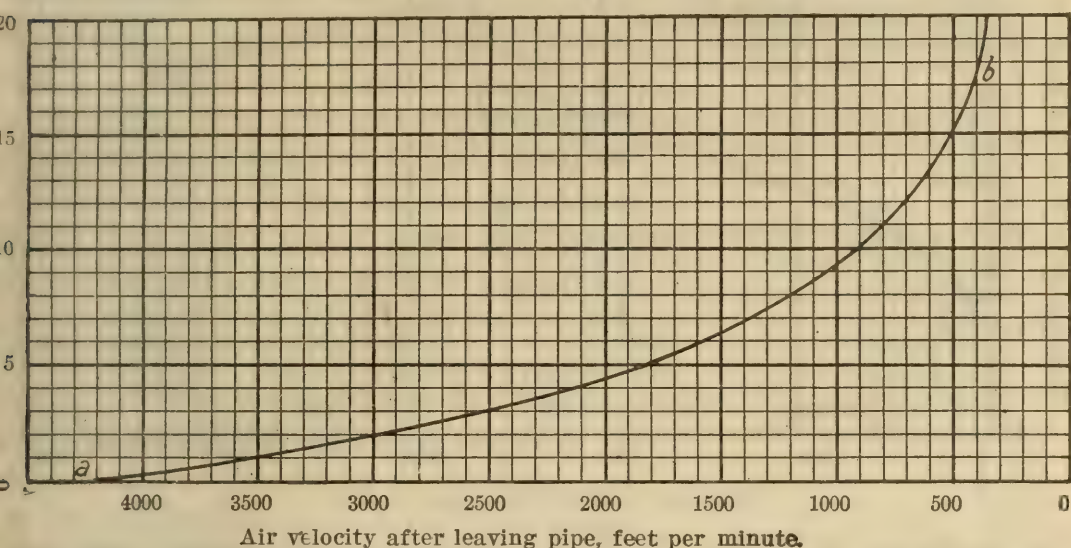


FIG. 18.—Decrease of velocity of air after leaving canvas pipe: *a*, End of canvas pipe; *b*, breast of drift. Used 450 ft. of 8-inch canvas pipe taking air at $70\frac{1}{2}^{\circ}$ F. wet bulb, $73\frac{1}{2}^{\circ}$ F. dry bulb, 86 per cent humidity, and discharging at 73° F. wet bulb, 81° F. dry bulb, 68 per cent humidity; had $7\frac{1}{2}$ -h. p., 2,200-volt motor direct connected to No. 2 Sirroco fan intaking 1,600 cu. ft. a min. and discharging at end of canvas pipe 1,500 cu. ft. a min.

bered crosscut, an increase of about 0.3° per 100 feet of travel. As the increase can not be ascribed either to rock or to water temperature, and there was absolutely no heating from outside sources, oxidation and friction must be considered as the probable cause. The volume was only about 6,000 cubic feet, but as the velocity was only about 200 linear feet per minute, it seems that the frictional heating is negligible. Oxidation, therefore, is probably responsible for the increase.

Inasmuch as veins carrying copper and iron sulphide ores in quartz gangue frequently have rock temperatures of 3° to 5° or more higher than veins on the same level carrying zinc sulphide in quartz, it is possible that iron and copper sulphides oxidize much more readily than do zinc sulphides.

Evidence of the readiness with which copper-iron sulphides oxidize is found in the fact that the copper precipitated from water which has been through a fire area in a copper mine frequently pays the cost of fighting the fire. The copper exists in the water as sulphate, oxidized from the sulphide. Copper sulphate readily dissolves in water but copper sulphide is insoluble in it. Moreover, though water from solid veins contains very little, if any, copper sulphate, and most Butte ores contain practically none, yet after a worked-out stope has been abandoned for a few years a profitable amount of copper can be precipitated from water run through it. Evidently copper sul-

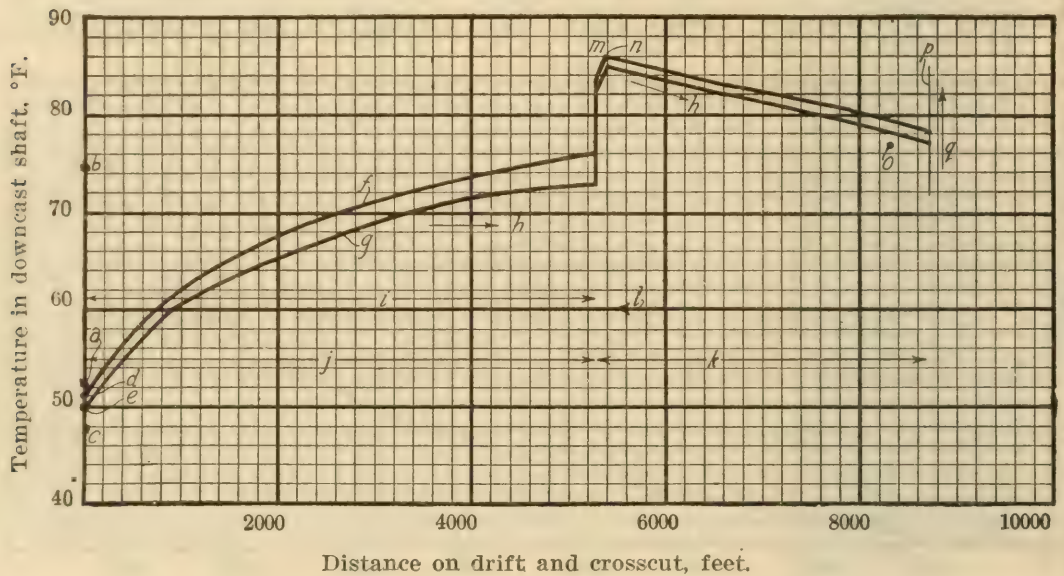


FIG. 19.—Data on air flow from downcast to upcast shaft showing influence of cool water drippers in downcast shaft and of air and rock temperatures on each other: *a*, Air at surface (shaft collar) dry bulb; *b*, wet bulb; *c*, copious flow of water like rain enters shaft about 100 ft. from surface at 48° F., water in shaft from 100 ft. to bottom (1,200 ft.); *d*, temperature of air downcast in shaft at 1,200-ft. station, dry bulb; *e*, same as *d*, wet bulb; *f*, dry bulb; *h*, direction of air; *i*, natural rock temperature on 1,200-ft. level; *j*, 1,200-ft. level; *k*, 800-ft. level; *l*, natural rock temperature on 800-ft. level but no known fires; *o*, present rock temperature in return air course 200 ft. from upcast shaft on 800-ft. level; *p*, upcast shaft; *q*, to surface.

phide oxidizes readily at mine temperatures, as much copper water comes from abandoned stopes that have never had fires.

It is well known that in many mining regions copper-iron sulphide ores fire with great readiness, though there is no definite record of their spontaneous firing in Butte; on the other hand, the writer has no knowledge of the zinc sulphides firing in any mine.

Figure 20 shows a plan of two drifts off a crosscut, one drift being in quartz and zinc sulphide ore and under new stopes, the other drift being in quartz and copper-iron sulphide and under old stopes with considerable decaying timber. In still air in the zinc sulphide drift the temperature was 78° F.; in still air in the copper-iron sulphide drift at a point only a few hundred feet distant the temperature

was 81°. Except the factor mentioned, the only factor that might have affected the temperature was water at a temperature of 77° flowing from the solid rib of the sulphide drift at a point about 150 feet, where a temperature of 81° was taken. This temperature in water flowing from solid rock would seem to fix the rock temperature at about 77°, hence the 81° temperature under the old copper-iron sulphide stope was 4° or 5° higher because of oxidation; seemingly neither the comparatively new timber in the zinc sulphide stope nor the zinc sulphide ore had yet started to heat.

Though zinc sulphides are not readily oxidizable under ordinary mining conditions, it must not be inferred that mines having zinc sulphide ores are free from oxidation; in one of the large zinc-producing mines of Butte, rock temperatures taken on a certain level were 10° lower than the temperature of air coming out of abandoned stopes, on the same level, filled with waste and old timber. As the stopes were above the level, the natural rock temperatures in them should be slightly lower than those on the level. It is possible that some or all of this excess temperature might be due to heat generated by rock movement, as the old workings of this mine are subject to such movement.

One of the most objectionable features of the present ventilation practice in Butte mines is the slight attempt made to prevent air in abandoned stopes with a temperature higher than that of the air in air courses from contaminating the latter. At one mine nearly 5,000 cubic feet of air per minute, at a temperature of 90° F. and with an excessive CO₂ content, was allowed to come from abandoned workings, to mix with the entire down-cast air supply of the mine. The natural rock temperature of the old workings should not have been over 80°, the excess being due probably to the heating of timber.

Figure 21 shows fresh air at 70° F. becoming mixed with air at 80° from an abandoned stope, giving a temperature of 75° F. to the

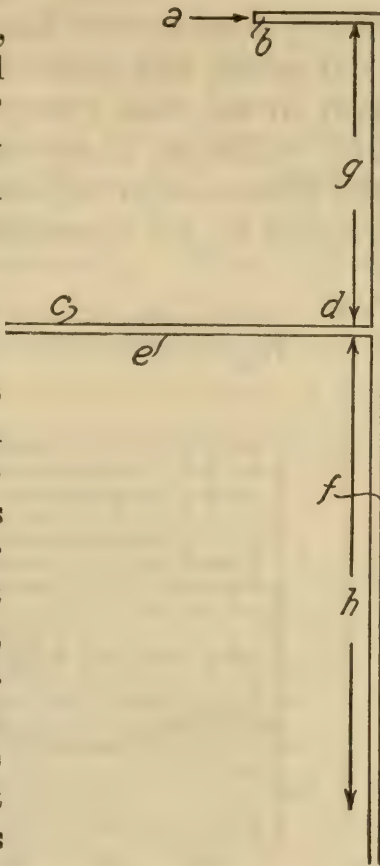


FIG. 20.—Temperature differences between different veins at the same depth; possible effects of oxidation: *a*, 70° F. wet bulb; 76° F. dry bulb, relative humidity 96 per cent, still air in drift under stope; *b*, ore, dry quartz carrying rhodonite and sphalerite, new stope, not much timber, width 5 ft.; *c*, water from solid 77° F.; *d*, damp quartz-granite carrying bornite and chalcopryrite, old stope, much timber, some signs of decay of timber, width 5 ft.; *e*, 80° F. wet bulb, 81° F. dry bulb, relative humidity 96 per cent, still air in drift under stope; *f*, little or no air circulation; *g*, 400 ft.; *h*, 1,100 ft. to shaft.

mixed air which was later used by working places. In addition to increasing the temperature of the fresh air by 5° , this vitiated air raised the humidity from 63 per cent to 74 per cent.

Butte mines contain more than 3,000,000,000 feet, board measure of timber used underground since mining began. Of this timber probably 2,500,000,000 feet or more is in the group of big interconnected mines, and most of it is exposed to a slow-moving total air supply of less than 1,600,000 cubic feet per minute. Heating from timber oxidation alone undoubtedly raises the air temperature in Butte mines several degrees. Much if not all of this heating could be prevented by the systematic sealing of abandoned workings. The

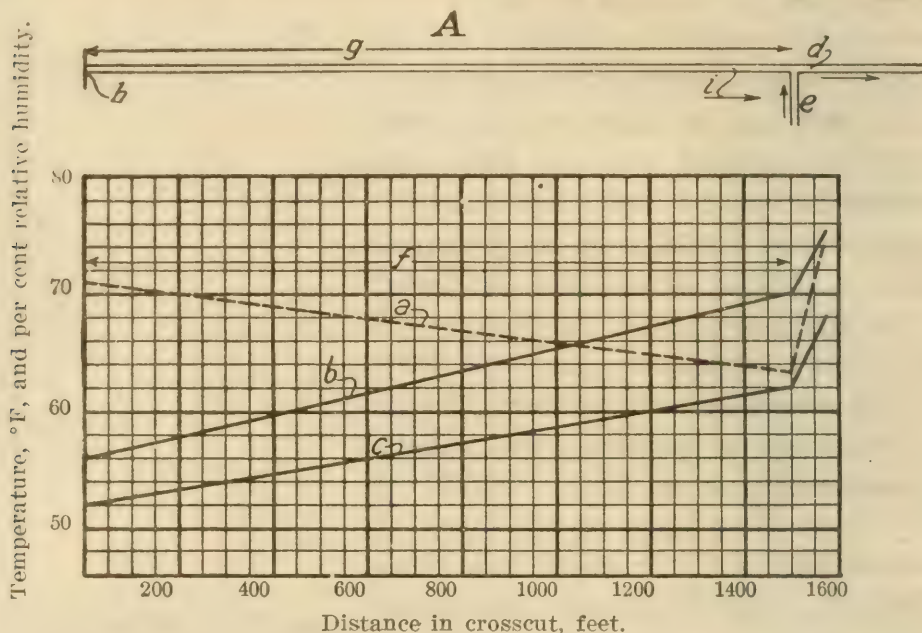


FIG. 21.—Contamination of fresh air by air from old stopes: A, Plan of drift; a, relative humidity; b, dry-bulb temperature; c, wet-bulb temperature; d, air (combined flow) 69° F., 74 per cent humidity; e, air 78° F. wet bulb, 80° F. dry bulb, 91 per cent humidity, out of abandoned stopes; f, 1,500 ft. of dry unintersected crosscut; g, 1,500 ft. of dry unintersected crosscut, air velocity 400 ft. a min.; h, temperature 51° F. wet bulb, 56° F. dry bulb, 71 per cent humidity; i, direction of air, velocity 400 ft. a min., 62° F. wet bulb, to 70° F. dry bulb, 63 per cent humidity.

appendix (p. 125) gives results showing that in laboratory experiments the absorption of oxygen by timber proceeded practically simultaneously with the formation of CO_2 , presumably a chemical reaction that gives off heat. As the tests were on a laboratory scale no record could be kept of changes in temperature.

Table 7 (p. 38) illustrates the effect of oxidation in one Butte mine that has natural ventilation, and hence is poorly ventilated. Although this mine employs about 300 men underground per shift, only 15,500 cubic feet of air per minute come out of it, this representing the total air supply from all sources. Although no workings are below the 1,500-foot level and at least one-half of all work is above the 1,200-foot level, practically all the natural rock temperatures being in con-

sequence not above 80° F., and in more than half of the working places not above 75°; yet temperatures in practically all stopes, as well as at the face of drifts and crosscuts, are above 80° F. Moreover, the return air temperature of this shallow mine is 76½° F. as against 73° F. (Table 3) at a large fan-ventilated mine that has 90 per cent of its workings below the 2,000 level, where rock temperatures are all above 80° F. and many are higher than 100° F. In the latter mine where rock temperatures are high, the air course velocities approach 1,000 linear feet per minute, but in the mine having natural ventilation it is almost impossible to find a velocity in excess of 300 feet per minute, and in most places the current is too weak to be measured with an ordinary anemometer. Thus, although the natural rock and water temperatures are low and the air velocities are so slow that heating through friction is a minimum, the average excess temperature of 10° F. in working places is probably due almost wholly to the oxidation of timber and possibly of copper and iron sulphides.

MINE FIRES.

Mine fires extinguished within a few days, weeks, or, perhaps, months have temporarily increased the temperature of mine air—directly through radiation and convection and indirectly through the interruption of ordinary ventilation. The Butte mining district has been unfortunate, however, in that a number of fires have burned for many years in worked-out regions, feeding on timber and finely divided sulphides, and have extended considerable distances laterally and in depth. The most widely known and probably the most extensive of these fires has affected much ground in Anaconda, Neversweat, and St. Lawrence mines, from the 500 to the 2,000 levels, and has burned continuously since 1889. Another well-known and expensive fire that has been burning for many years is in the Leonard mine. It affects the Leonard, East Colusa, Tramway, and Rarus mines from the 500 to the 2,000 levels. A fire in the Mountain View mine, not as extensive as those mentioned, affects that mine and the West Colusa.

These fires not only heat the adjacent rock to high temperatures but complicate the handling of air currents, even compelling at times the temporary abandonment of fans. Moreover, as nearly all Butte mines are interdependent for ventilation, the heated air from a fire in one mine is frequently carried to other mines. A more serious trouble, however, is that to work veins parallel to the one in which the fire is burning, or to work the burning vein below or above the fire area, air courses must be made through burning material or through rock intensely heated by the fire. In consequence, high air temperatures and frequently mine fire gases are encountered.

TABLE 7.—Analyses of air from poorly ventilated places in mine A, one of the best ventilated mines in Butte.

Place.	Wet bulb, °F.	Dry bulb, °F.	Relative humidity, per cent.	CO ₂	O ₂	CO	CH ₄	N ₂	Velocity, feet per minute.	Quantity, cu. ft. per min.	Remarks.
Main return	71½	71½	100	0.31	20.16	0.00	0.00	79.53	660	33,200	Main and total return for mine with about 450 men underground per shift.
Do.	70½	71	98	0.30	20.25	0.00	0.00	79.45	600	18,000	
Average and total....	71	71½	99	0.30½	20.20½	0.00	0.00	79.49	630	51,200	
Outside air.....	56	78½	.....	0.03	20.93	0.00	0.00	79.04	.....	.....	Taken in a stope on 2,000.
Compressed air.....	.....	.....	.....	0.05	20.84	0.00	0.00	79.11	.....	.....	
Stopes.											
Thirteenth floor, 1,807 B vein.	82	83½	94	0.45	19.95	0.00	0.00	79.60	None.....	(?)	Stope hot, humid, uncomfortable.
Twentieth floor, 2,014 C vein	80½	82	94	0.12	20.67	0.00	0.00	79.21	.....	.....	Do.
Eleventh floor, 2,056 C vein.	82½	83	98	0.08	20.80	0.00	0.00	79.11	.....	.....	Do.
Twentieth floor, 2,056-E.	82½	83½	96	0.21	20.52	0.00	0.00	79.27	Slight.....	(?)	Do.
M. vein.	84	85	96	0.18	20.54	0.00	0.00	79.28	do.....	(?)	Do.
Twenty-second floor, 2,446 Rill vein.	73	74	95	0.46	19.94	0.00	0.00	79.60	None; damp..	(?)	Old gob; no shooting; bad air.
Sixth floor, 453 Spec. vein...	74	75	95	0.55	19.80	0.00	0.00	79.65	do.....	(?)	Old gob; makes men sleepy.
Fifth floor, 456 Spec. vein...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
Averages.....	.....	.....	.....	0.29	20.32	.....	.....	79.39	.....	.....	
Drifts and crosscuts.											
1,854 B drift.....	77½	77½	100	0.20	20.56	0.00	0.00	79.24	50	1,500	From abandoned stopes.
2,003 F drift.....	74	76	91	0.17	20.73	0.00	0.00	79.10	None; dry....	.....	Breast; explosive fumes (?).
2,202 C drift.....	78	80	92	0.15	20.66	0.00	0.00	79.19	(?)	.....	From working stopes.
2,200 Spec. drift.....	84	85	96	0.15	20.66	0.00	0.00	79.19	100	3,000	From adjoining mine.
2,401 crosscut.....	80	83	88	0.23	20.52	0.00	0.00	79.25	None.....	.....	Breast; explosive fumes.
2,801 crosscut.....	89	89	100	1.91	18.28	0.00	0.00	79.81	do.....	.....	700 feet from breast; abandoned crosscut.
1,675 N. crosscut.....	82	82	100	0.45	20.12	0.00	0.00	79.43	130	4,000	From abandoned stopes.
1,673 S. crosscut.....	86	90	85	0.46	20.14	0.00	0.00	79.40	(?)	(?)	Do.
652 drift.....	64½	65	98	0.93	19.41	0.00	0.00	79.66	None.....	(?)	Breast gob, damp; explosive fumes (?).
2,203 F drift.....	78½	79	98	0.45	20.37	0.00	0.00	79.18	do.....	.....	Breast wet; heavy timber and no work several days.
1,875 F drift.....	75	76	96	0.61	19.49	0.00	0.00	79.93	do.....	.....	350 feet from breast; smoke from explosives.
Average, drift breasts.	.....	.....	.....	0.42	20.19	0.00	0.00	79.39	.....	.....	
Average, drifts from abandoned places.	.....	.....	.....	0.63	19.85	0.00	0.00	79.42	.....	.....	

Raises.	81	82½	94	0.07	20.81	0.00	0.00	79.12	None	Hot, uncomfortable; explosive fumes (?). Do. Do. Extremely oppressive. Very uncomfortable. 5 minutes after shooting one hole.
Third floor, 2,262 B.	81	82½	94	0.07	20.81	0.00	0.00	79.12	None	
First floor, 2,254 B.	83	84	96	0.26	20.56	0.00	0.00	79.18	do.	
Seventh floor, 2,211 F.	80½	81	97	0.38	20.48	0.00	0.00	79.14	do.	
Sixth floor, 2,442 E. M.	91½	93	94	0.36	20.06	0.00	0.00	79.58	do.	
Fifth floor, 2,850 E. M.	87	88	96	0.10	20.88	0.00	0.00	79.02	do.	
First floor, 754.	76½	76½	100	0.16	20.47	0.00	0.00	79.37	do.	
Averages.				0.22	20.54	0.00	0.00	79.24		

NOTE.—Air samples taken at working faces only when some unusual conditions were encountered or suspected; mine uses exhaust fans on surface at upcast shafts.

It is not possible to give exact figures on the increase of temperature underground through mine fires; air temperatures of 90° and more, however, are frequently encountered in workings where temperatures from natural causes should be 80° or less. It is certain that in some mines the average temperatures are increased as much as 5 to 10° F. from fires alone. A partial measure of the heating effect of mine fires may be gained from the fact that the temperature of the water pumped from the Leonard mine, where mine fires are being fought with large quantities of water, frequently runs above 95° F., whereas water pumped from the High Ore and other properties rarely exceeds 85° . Probably a more direct measure of the effect of mine fires on the temperature of working places in a mine is afforded by the following data from a mine that has a long-standing fire in one vein but is working numerous other veins. The average dry-bulb temperature of the 24 places being worked on the vein in which the fire was burning was 85.6° F., and many of these places were far enough from the fire to be essentially outside its influence. The average dry-bulb temperature, in the same mine, of 61 places being worked in about eight or ten other veins without fire and approximately at the same vertical depth was 79.8° F. Hence in the working places of this vein the increased temperature due to the mine fire was over 5.8° F., and warm air from the fire area probably raised the temperature of many of the 61 places outside the burning vein 1° or more.

FRICTIONAL HEATING OF AIR.

The heating of air currents by the frictional resistance to their movement through mine workings is difficult to measure, but it certainly is of some importance. Part of the increased temperature of the downcast air in Figures 4, 5, 7, and 9 (pp. 16, 17, 23, and 25) is due to friction, though a study of Figure 11 (p. 27) indicates that the amount is not very great. Figure 9 (p. 25) shows that downcast air increased 0.66° F. per 100 feet of shaft traversed at 500 to 700 linear feet per minute, and increased 0.93° per 100 feet of crosscut traversed at 390 to 400 feet per minute. The higher rock temperature of the crosscut seems to have had more effect on air temperature than did the much greater velocity in the shaft. The fact, however, that the cross-sectional area of the crosscut was only 35 square feet with a perimeter of 24 square feet compared to the 70 square feet area and 38 feet perimeter of the shaft may account in part for the high rate of the increase of temperature with lower velocity in the crosscut.

Figure 9 (p. 25), on the other hand, offers proof of considerable increase of air temperature wholly independent of rock and water temperature, hence due either to friction or to oxidation, or both. In traveling 900 feet from the downcast shaft at 150 feet per minute

through a damp untimbered crosscut, the air gained $10\frac{1}{2}^{\circ}$ F., or 1.17° per 100 feet traveled, $61\frac{1}{2}^{\circ}$ being exactly the rock temperature of the place. In 4,300 linear feet more of travel, at approximately 125 to 150 linear feet per minute, through the damp partly timbered crosscut, the temperature increased from $61\frac{1}{2}^{\circ}$ to 76° or 0.33° per 100 feet traveled. None of this increase can be attributed to rock or water temperature, as each was below 62° F.; moreover, there was no access of hot air from any other workings. The increase therefore was probably due to friction and oxidation.

In open shafts and crosscuts it is difficult to separate the amount of heating due to friction from that due to rock and water and to oxida-

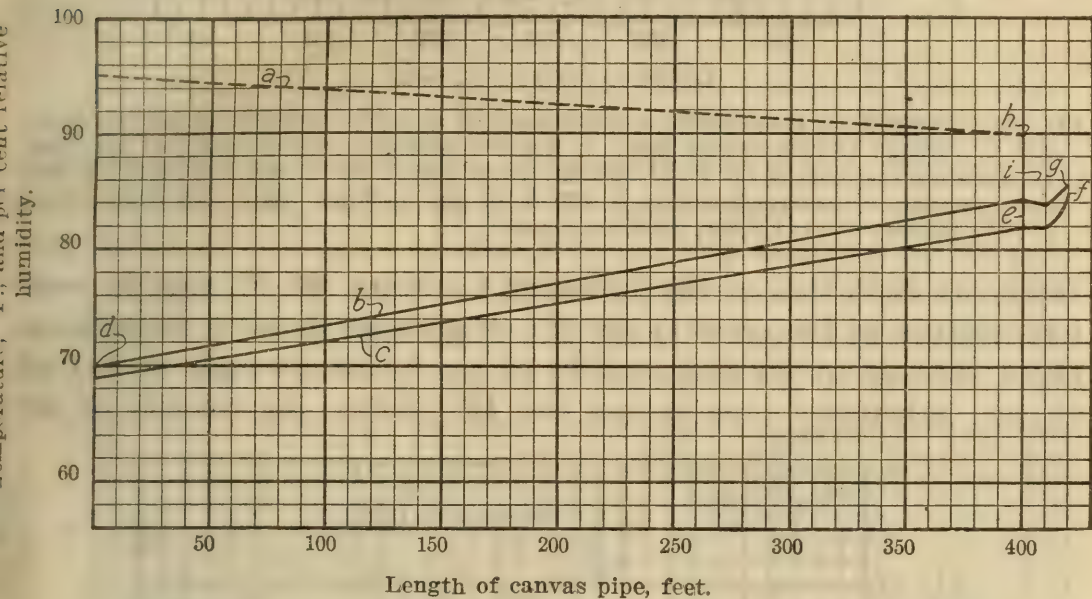


FIG. 22.—Effect of flow through 400 ft. of 8-inch canvas pipe, using No. $2\frac{1}{2}$ fan and $7\frac{1}{2}$ -h. p. motor: *a*, Relative humidity; *b*, dry-bulb temperature; *c*, wet bulb; *d*, water gage $3\frac{1}{4}$ in.; *e*, water gage $\frac{1}{2}$ in.; *f*, water on floor at breast, 85° F.; *g*, air at breast, fan not working; *h*, discharge end of pipe; *i*, compressed-air blowers. Velocity at discharge end of pipe, 3,500 ft.; volume, 1,800 cu. ft.; intake air 69° F. to 70° F., 95 per cent humidity; discharge air 82° F. to $84\frac{1}{2}^{\circ}$ F., 90 per cent humidity; increase of temperature per 100 ft. of pipe, wet bulb 3.25° F., dry bulb 3.62° F., decrease of relative humidity, 1.25 per cent.

tion, but there is no such trouble in observing the flow of air in canvas and galvanized iron tubing, particularly when short lengths (less than 500 feet) only are used. Figure 16 (p. 31) shows the dry-bulb temperature rose $6\frac{1}{2}^{\circ}$ in 300 linear feet of 10-inch canvas pipe, the velocity being 4,800 feet per minute; here is an increase of 2.17° F. per 100 feet traveled, a remarkable amount, as only $1\frac{1}{4}$ seconds are required to travel 100 feet at a velocity of 4,800 feet per minute.

Figure 22 shows an increase of 3.62° F. per 100 feet in traversing 400 feet of 8-inch canvas pipe at a velocity of 3,500 linear feet per minute; the dry-bulb temperature increasing $14\frac{1}{2}^{\circ}$ F. between intake and discharge. Figure 23 shows an increase of 2.17° F. per 100 feet

in traversing 300 feet of 16-inch canvas pipe at a velocity of slightly over 4,000 feet per minute, the temperature of the intake air at the

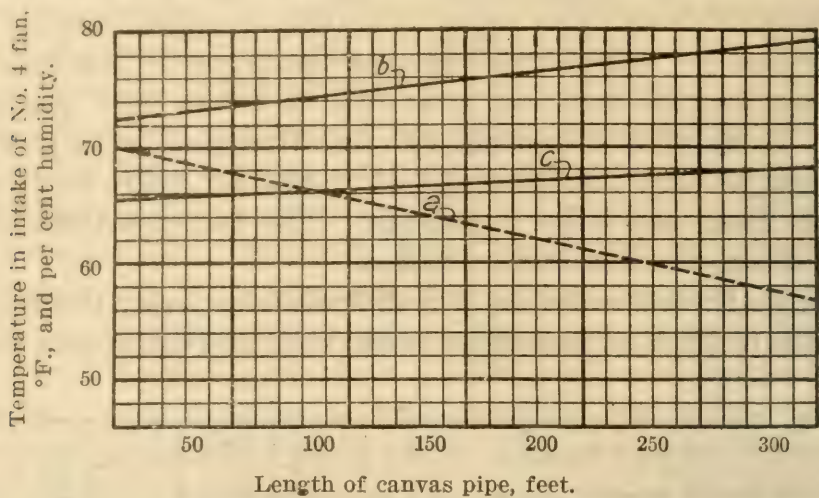


FIG. 23.—Increase of temperature and decrease of relative humidity in air traveling 300 ft. through 16-inch canvas pipe: *a*, Relative humidity; *b*, dry bulb; *c*, wet bulb. Temperature increase to 100 ft. of 16-inch canvas pipe, 0.83° F. wet bulb, 2.17° F. dry bulb; decrease of relative humidity to 100 ft. of pipe, 4.33 per cent; rock temperature, 86° F.; velocity of air in pipe, 4,000 ft. a min.

fan being $72\frac{1}{2}^{\circ}$, that of the discharge air being 79° F., and the rock temperature of the crosscut 86° F. Figure 24 shows a remarkably rapid increase of the temperature of air forced through 60 feet of 16-inch galvanized pipe having two 45° elbows, the velocity of air

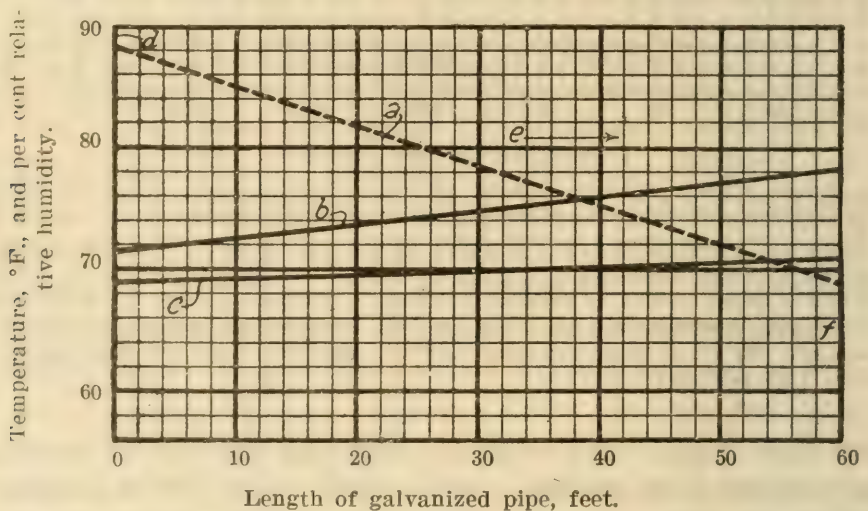


FIG. 24.—Rapid increase of temperature and decrease of humidity in air forced through 16-inch galvanized pipe at velocity slightly over 6,000 ft. a min.: *a*, Relative humidity; *b*, dry bulb; *c*, wet bulb; *d*, No. 4 fan, 20-h. p. motor; *e*, direction of air flow, velocity over 6,000 ft. a min.; *f*, rock temperature 85° F. The pipe was but 60 feet long and had two 45° elbows.

	In 60 ft. of pipe.	In 100 ft. of pipe.
Temperature increase, dry bulb	7° F.	11 $\frac{3}{4}$ ° F.
Temperature increase, wet bulb	2° F.	3 $\frac{1}{2}$ ° F.
Relative humidity decrease	19 per cent	31 $\frac{3}{4}$ per cent

being approximately 6,000 feet per minute; the intake air was $71\frac{1}{2}^{\circ}$ and the discharged air $78\frac{1}{2}^{\circ}$ F., a difference of 7° in 60 feet of pipe

or at a rate of $11\frac{2}{3}^{\circ}$ increase per 100 feet of pipe; the rock temperature was 85° .

Figure 25 shows the increase of dry-bulb temperature in a short length (about 100 feet) of 16-inch canvas pipe, with two 45° and one 90° galvanized elbows; it also shows a simple method of counteracting that increase. The results are as follows:

	Di- am- eter of pipe, in.	Length of pipe, ft.	Ve- loc- ity, air in pipe, ft. a min.	Vol- ume, air in pipe, cu. ft. a min.	Intake tempera- ture.			Discharge tem- perature.			Increase per 100 ft.		
					Wet bulb, $^{\circ}$ F.	Dry bulb, $^{\circ}$ F.	Rel. hum., per cent.	Wet bulb, $^{\circ}$ F.	Dry bulb, $^{\circ}$ F.	Rel. hum., per cent.	Wet bulb, $^{\circ}$ F.	Dry bulb, $^{\circ}$ F.	Rel. hum., per cent.
Without spray...	16	95	6,700	8,900	74	79	79	75	84	66	1.1	$5\frac{1}{2}$	13.
With spray, water 67° F.....	16	115	6,700	8,900	68.5	73	78	70	73	86	1.3	0	7.0

The air velocity was 6,700 linear feet per minute and the increase of temperature (dry bulb) was 5° in 95 feet of pipe or $5\frac{1}{2}^{\circ}$ per 100 feet. Subsequently water at 67° F. temperature was sprayed by compressed air through a quarter-inch opening at a rate of 100 gallons per eight hours into the intake of the fan, and with all other conditions similar, except a slight increase in the length of the 16-inch canvas pipe, the temperatures of the intake and of the discharge

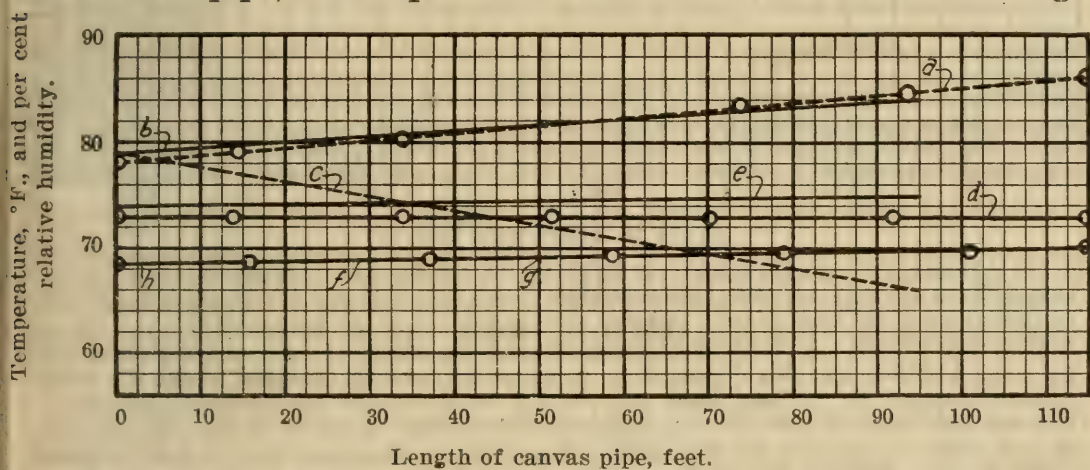


FIG. 25.—Cooling effect of water spray in 16-inch canvas pipe; No. 4 fan intake, 20-h. p. motor; natural rock temperature, 87° F.; two 45° and one 90° elbows in the pipe line: *a*, Relative humidity (with spray); *b*, dry bulb (without spray); *c*, relative humidity (without spray); *d*, dry bulb (with spray); *e*, wet bulb (with spray); *f*, wet bulb (without spray); *g*, water gage $\frac{1}{2}$ inch.; *h*, water gage $1\frac{1}{2}$ inch.

air were the same; the discharge air with spray arrived at the end of the pipe at a temperature of 73° compared to 84° without spray. The rock temperature of the place at the discharge end of the pipe was 87° F.

Figure 26, on the other hand, shows that practically saturated air with high velocity and high temperature actually lost temperature in flowing through canvas pipe. Air at 82° dry-bulb temperature,

98 per cent relative humidity, was forced from the top of a manway through 2,200 linear feet of 16-inch canvas tubing in a crosscut at a velocity of 4,200 linear feet per minute at the point of discharge, the air leaving the pipe at $79\frac{1}{2}^{\circ}$ F. and 100 per cent relative humidity. The flowing air deposited so much water in the pipe that drainage had to be provided. The probable reason for the decrease in air temperature, instead of the usual increase of 1° F. or over per 100 feet of pipe, is that the rock temperature in the crosscut was $72\frac{1}{2}^{\circ}$ F. and

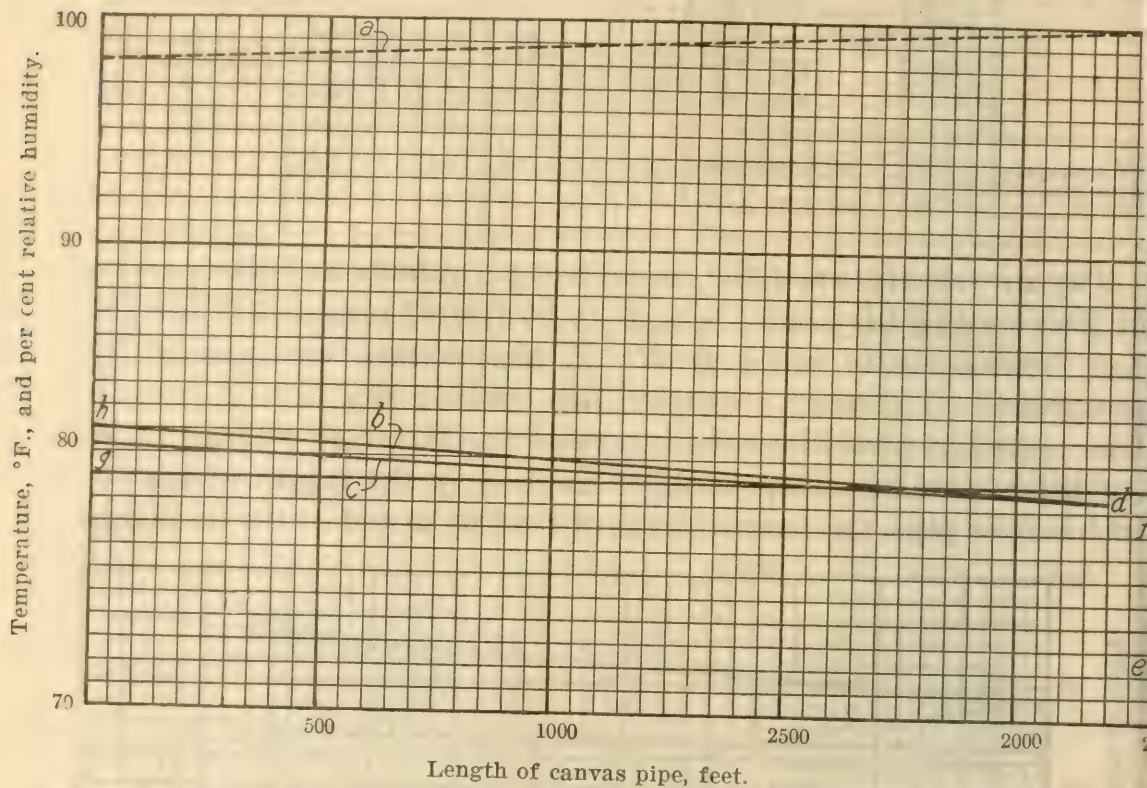


FIG. 26.—Changes in temperature and humidity of air by flow through 16-inch canvas tubing for 2,200 feet: *a*, Relative humidity; *b*, dry bulb; *c*, wet bulb; *d*, discharge end of canvas pipe, air $79\frac{1}{2}^{\circ}$ F. wet and dry bulb, 100 per cent relative humidity; *e*, water from breast $72\frac{1}{2}^{\circ}$ F.; *f*, damp rock, breast of crosscut, air 78° F. wet and dry bulb, 100 per cent humidity; *g*, No. 4 fan, 30-h. p. motor; *h*, at top of raise, intake air from 2,200-foot level 81° F. wet bulb, 82° F. dry bulb, 98 per cent relative humidity; original rock temperature $72\frac{1}{2}^{\circ}$ F., approximately; water drippers, various places, 72° F. wet bulb, to 75° F.; velocity 4,200 ft. a min., at discharge end of pipe, volume 5,500 cu. ft.; decrease to 100 ft. of pipe, wet-bulb temperature, 0.09° F.; dry bulb, 0.12° F.; increase of relative humidity, 0.09 per cent to 100 ft. of pipe.

water drippers, temperature 72 to 75° , fell on the pipe continuously at many points.

There can be no doubt as to the generation of heat in a rapid air current through frictional resistance, yet the exact increase for shafts, drifts, or crosscuts can not be separated from the increase through rock and water temperature, and oxidation; and although in metal mines the air passages, especially drifts and crosscuts, have much rougher walls and are more irregular than in coal mines, and have small cross-sectional areas, still the total heating effect of friction, under present conditions, can not be great, for air velocities in

metal mines are comparatively slight. With the use of metal and canvas tubing, however, a definite idea of the influence of friction can be formed.

MOVEMENT OF GROUND.

As has been noted in Butte mines, different veins on the same level have different rock temperatures; generally the one with the higher rock temperature is a fault vein in which there has been and is rock movement. All fault veins, however, do not show a higher temperature, particularly if the vein material is wet or if there are streams of water flowing from the vein. In mines having wide veins or deposits there are caves or runs of considerable quantities of ore at times, and almost invariably these runs are accompanied by a rise of temperature.

These runs are small manifestations of what must be taking place on a wider scale in all of the older and larger mines of the district. Butte veins have a general dip of 70° to 80° from the horizontal and roughly parallel each other at frequent intervals, being only a few hundred feet apart; hence the footwall of one vein is the hanging wall of another. When the ore is removed there is a tendency for all the ground between the veins to settle. The fact that there is much local movement taking place constantly is proved by the immense amount of effort required to keep the Butte shafts open, few shafts being free of movement. It often happens that the upper part of a shaft moves its full width in two or three years. That this ground movement, or settlement, is taking place on a gigantic scale is proved by level surveys of the United States Coast and Geodetic Survey,² which show that the United States post office building at Butte had been lowered $10\frac{5}{8}$ inches in elevation in a two-year period. So widespread was the ground settlement, however, that there is little evidence of it in the streets, and the post office building shows little or no cracking of walls.

During the years 1916, 1917, and 1918, Butte mines produced over 6,000,000 tons of ore annually, and probably more than that amount of waste was moved either to the surface or to other parts of the mines. A conservative estimate of the tonnage handled during the 50 or more years of mining in Butte is over 100,000,000 tons of ore and a like tonnage of waste. Assuming 15 cubic feet to the ton of ore and waste, it seems probable that the underground space at Butte from which the original material has been moved amounts to 3,000,000,000 cubic feet at least, or 1 foot over an area of 70,000 acres. As the active mining district from which practically all of the above-mentioned material was taken covers only about 4,000 acres, it will be seen that the total depth of excavation under each acre averages nearly 18 feet.

² Weed, W. H., *Geology and ore deposits of the Butte district, Montana*. U. S. Geol. Survey Prof. Paper 74, 1912, p. 50.

To one who considers the enormous amount of material removed the fact that the veins dip at such angles that walls left with little support have a tendency to move, and the fact that a mass of ground weighing hundreds of millions of tons actually is moving, it is obvious that the amount of heat generated by the movement must be considerable, though the actual rate of movement is slow. Movement is shown by increased rock temperatures and increased oxidation of crushed timbers and ores.

The rock temperatures given in Table 6 are essentially independent of this movement, as they were taken in a mine on the outskirts of the well-worked district, and most of them were taken at depths at which there had been little excavation, hence they would be practically unaffected by movement.

FIRING OF SHOTS.

More than 7,000,000 pounds of 30 to 40 per cent dynamite are used annually in Butte mines, and the total increase of temperature of the mine air through the use of explosives is probably not great, yet locally the effect may be important. In stopes, where there is considerable open ground and the charges of explosives are comparatively small, the increase of temperature from shots is not marked; but in more confined places—such as blind-end crosscuts, drifts, and raises—it is.

In one of the lower levels of a Butte mine a round of fourteen 5-foot holes drilled in the solid granite face of a 5 by 7 foot crosscut was charged with 155 sticks, $1\frac{1}{4}$ by 6 inches of 40 per cent gelatine explosive (about 70 pounds) and fired by electricity with No. 8 detonators. The holes were tamped to the mouth with clay in paper cartridges. The rock temperature, taken before loading the explosive in one of the upper holes, as well as in one of the lower holes filled with water, was 101° F., and the air in which the men worked while loading and tamping the holes had a dry-bulb temperature of $83\frac{1}{2}^{\circ}$, being supplied with air by fan and canvas pipe. As quickly as possible after the electrical firing of the entire round, air temperatures were again taken at the same place; the dry-bulb temperature was 98° , a rise of $14\frac{1}{2}^{\circ}$ F. in less than 3 minutes. What part of the increase of $14\frac{1}{2}^{\circ}$ in 3 minutes was due to the interruption of ventilation and consequent accession of heat from the rock, and what part was due to heat liberated by the explosive can not be stated definitely, yet it would seem improbable that the rock temperature of 101° could have caused more than half of the $14\frac{1}{2}^{\circ}$ increase in 3 minutes. No similar readings were taken in raises, but the effect in raises would undoubtedly be even greater than in a ventilated crosscut; in the crosscut mentioned the normal air temperatures were completely restored by ventilation within half an hour.

VOLUME OF AIR IN CIRCULATION.

Various countries, as well as our own States, have laws that stipulate definite quantities of air, as 100 to 300 cubic feet per minute per man employed, shall be in circulation underground, with two or three times as much additional for each horse or mule. Such laws provide enough air in some metal and in most coal mines if the distribution is adequate. When, as in Butte, however, the main feature affecting underground air conditions is rock temperature, the above provisions may be and probably are entirely inadequate. At least 20 of Butte's mines are operating eight to ten levels or more, many of them in ground having rock temperatures over 80°. Figures 10 and 11 (pp. 26 and 27) show that in drifts of ordinary size, 30 to 35 square feet of cross section and a velocity of 300 to 400 linear feet per minute—these figures giving a volume of 14,000 cubic feet per minute as a maximum—the air temperature increases approximately 1° F. per 100 feet traveled until the air and rock temperature become approximately equal. Little air going underground during any season of the year leaves downcast shafts at less than 60° F. at depths below the 1,000; hence, with 2,000 feet traveled even at the relatively high velocity of 400 feet per minute, mine air has reached a temperature of 80° F., in the opinion of the writer the maximum for mine efficiency. As 2,000 feet of travel frequently will cover only the sill workings on one level, the air, to be effective, should be used on only one level, requiring 14,000 linear feet per level as a minimum, or 140,000 cubic feet per minute for a mine having 10 working levels.

If, however, pairs of levels were taken for each split, using 14,000 to 20,000 cubic feet per minute, and the air removed from the mine after traversing that split, the result would probably be effective, and the maximum air demand for a large mine would be about 100,000 cubic feet per minute.

Where the velocity is less than 300 to 400 linear feet per minute in the main airways, the intake air becomes warmed at a much greater rate than 1° per 100 feet, and when slow-moving air has reached rock temperature it tends to become still warmer, through access of heat from friction and oxidation, as shown in Figure 10 (p. 26), and may then actually raise the temperature of the inclosing rock. Moreover, where the air supply is so scanty that air used in one part of a mine must be used in other parts, the heated air almost invariably moves upward, toward workings where rock temperatures are lower, and thus raises the rock temperatures there. One of the Butte mines took air at 71° F., relative humidity 100 per cent, out of an upcast shaft and coursed it through some upper workings having rock temperatures below 60° F. Condensation immediately took place, the air became misty, almost cloudy, and rock temperatures rose while air temperatures fell. On the other hand, mines that were

the hottest in the Butte district when their circulation was sluggish because of insufficient volume and poor control, have been made comfortable within the past few years by increasing the volume of air and systematically splitting and distributing it.

Compressed air, though used widely in unventilated mines in Butte for cooling purposes, may have in the aggregate a tendency to raise underground air temperatures when blowers are used. The temperature of compressed air at the compressor is frequently much above 100° F., and at shaft collars has been found to be 85° to 90° . When released as blowers in the upper levels where the rock temperature is around 65° to 70° the compressed air is often several degrees hotter than the mine air; and in the deeper workings where rock and air temperatures are higher, the air from blowers rarely has a tem-

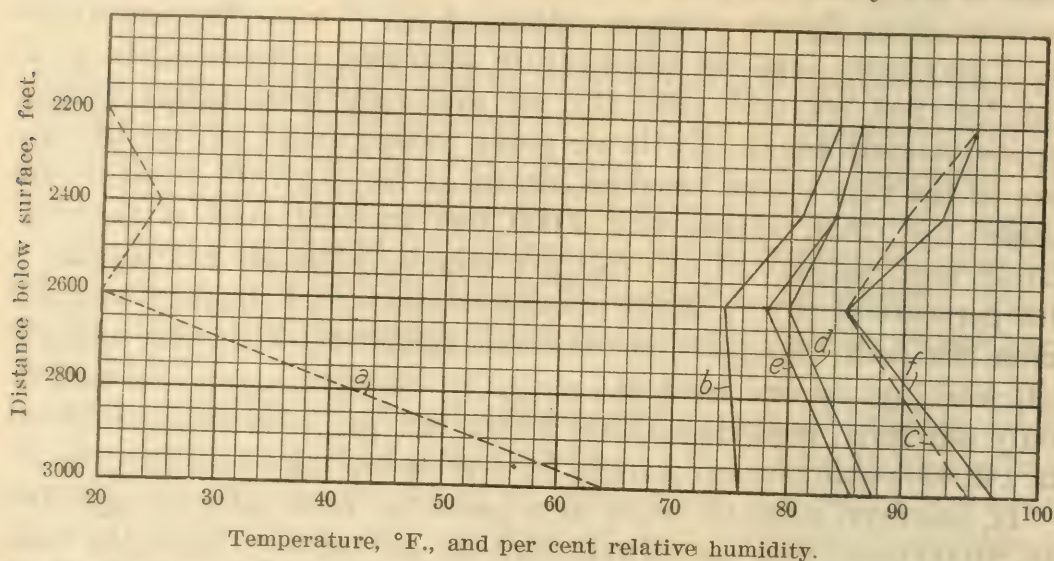


FIG. 27.—Temperature of compressed air and of surrounding air at various levels of a mine. Relative humidity: *a*, Compressed air at end of hose; *c*, 5 ft. from end of hose; *f*, mine air of working place. Dry-bulb temperature: *b*, Compressed air at end of hose; *d*, mine air at working places; *e*, 5 ft. from end of hose.

perature much more than a few degrees below that of the surrounding rock and mine air. (See Fig. 27.) It is true, of course, that the exhaust from drills escapes into the mine air at very low temperatures and has a well-defined cooling effect; the statements above apply solely to blowers, the compressed air from which has not had its energy reduced by doing work in a drilling machine.

MINE LIGHTS AND THE BREATHING OF ANIMALS.

Although the amount of heat given off by a miner's lamp and by his body is negligible in comparatively cool places, in open places with considerable volume of air, or in places when the air is moving, the combined effect of lights and breathing is appreciable in confined places where the rock temperatures are about 90° F., and there is no air circulation—such places as raises or breasts of drifts and crosscuts. In the latter places the air and rock temperatures usually

are about equal, the air temperature occasionally being 1 or 2 degrees lower because of compressed air or cool water, or both, being used in drilling. Frequently, however, when no drilling has been going on, nor compressed air blowing, the dry-bulb air temperature has been found to be 1° or even 3° higher than the rock temperature, the only probable cause being the heat of the bodies and the carbide lights of the two miners. In most Butte raises and in a large proportion of crosscut and drift breasts, miners perspire freely even without any exertion or work. Where rock is cool the air in confined places may be raised as much as 10 to 15 degrees or more higher than the surrounding rock by heat from miners' bodies. Underground stables, too, are frequently one or more degrees higher in temperature than the surrounding air or rock, and often are wholly without any circulation of air.

ELECTRIC MOTORS.

Like miner's lights and the bodily heat of miners, the aggregate effect of the heat from electric motors underground in Butte is almost negligible; but locally it is important, especially in underground stations which generally are in confined places and absolutely without ventilation. Such places have temperatures as much as 5° higher than surrounding rock and air, and if the underground stations are large they may have a definite influence in raising the air temperature of near-by working places.

AIR FROM ADJOINING MINES.

On account of the interventilation of the mines in the Butte district, the prevalence of high rock temperatures, and the existence of mine fires, most of the mines receive heated, vitiated air from adjoining mines. In some mines the entering air for ventilation has already ventilated parts of another mine and has a temperature over 80° or even 90° F. It is probably a conservative statement that in nearly every Butte mine the air owes at least one or two degrees, probably more, of increased temperature to heated air from an adjoining mine. This fact is one of many reasons why the interventilation of mines is inefficient or even dangerous.

FACTORS INFLUENCING THE RELATIVE HUMIDITY OF MINE AIR.

RELATIVE HUMIDITY OF SURFACE AIR.

Figures 5 (p. 17) and 28 and Table 5 present data on the constancy of the relative humidity at certain seasons in the year at certain points in a comparatively dry downcast timbered shaft carrying over 50,000 cubic feet of air per minute at a velocity of about 800 linear feet. Table 5 shows that, irrespective of surface temperature and humidity, the humidity in the shaft soon exceeded 60 per cent, and compara-

tively few readings were below 70 per cent. Moreover, there is surprisingly little variation in the readings of relative humidity in the shaft at the 2,000 to 3,000 foot stations during the winter, even though the humidity of the surface air shows wide changes from day to day. Figure 5 shows a seasonal difference of 10 per cent between

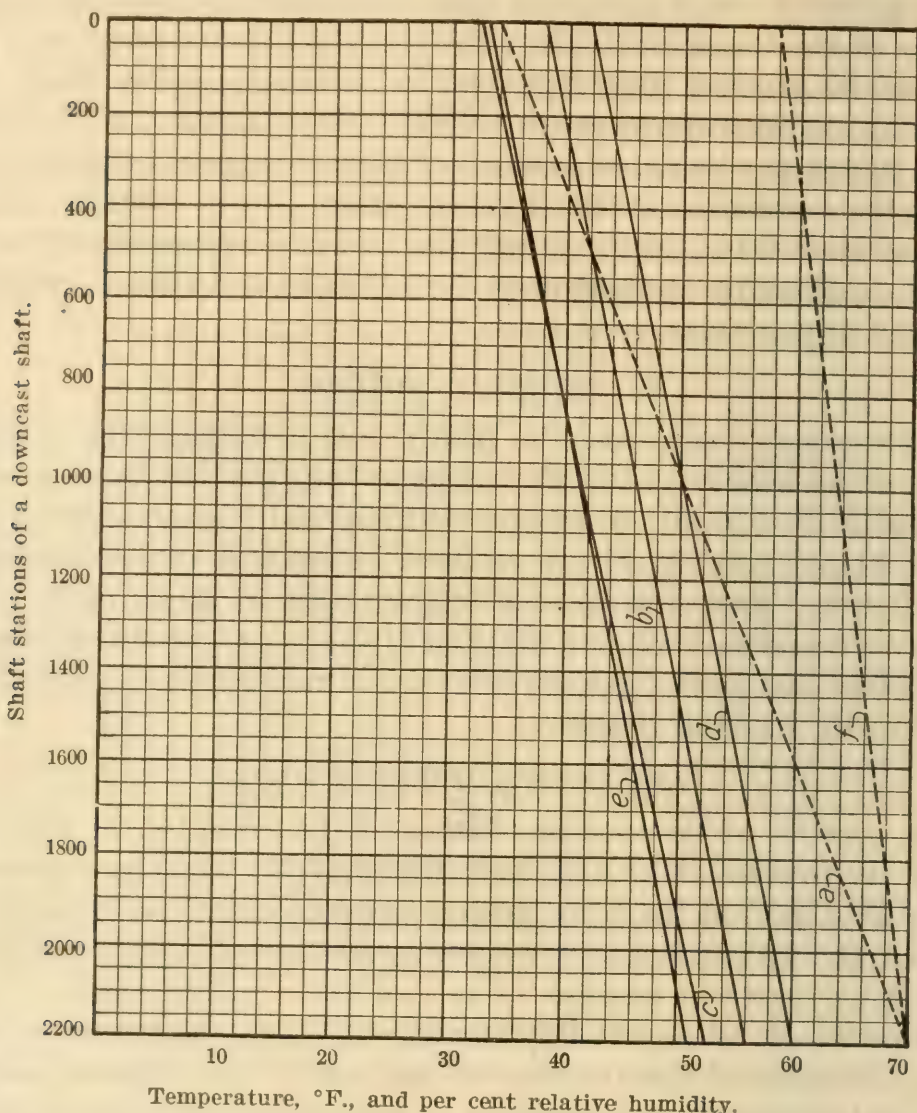


FIG. 28.—Constancy during winter of the relative humidity at the 2,200-foot station of a downcast shaft: *a*, Relative humidity, Dec. 1, 1917; *b*, dry bulb, Nov. 17, 1916; *c*, wet bulb, Dec. 1, 1916; *d*, dry bulb, Dec. 1, 1917; *e*, wet bulb, Nov. 17, 1916; *f*, relative humidity, Nov. 17, 1916. Relative humidity at surface, Nov. 17, 1916, 58° F.; Dec. 1, 1917, 34° F.; at 2,200-ft. shaft station both dates, 70° F. Average winter relative humidity at 2,200-ft. shaft station, 72.5° F. Velocity of air in shaft approximately 800 ft. a min.; volume, 50,000 cu. ft. a min.

summer and winter humidity, the winter humidity being the lower. Figure 28 shows the constancy of relative humidity at the 2,200-foot station in winter in spite of a wide range of surface humidity on two days—58 per cent on one day and 34 per cent on the other; on both days the relative humidity in the shaft at the 2,200 station was

70 per cent. Figure 32 gives similar data for summer in another downcast shaft.

Figure 7 (p. 23) shows changes in humidity at various points in the first-mentioned downcast shaft when the outside air was $29\frac{1}{2}^{\circ}$ F. From 100 per cent, with a low temperature, at the 400-foot station, the humidity gradually decreases with a rapid increase of temperature until at the 2,200-foot station the winter humidity remains constant at about 73 per cent, irrespective of surface humidity. From the 2,200 level downward there is a rapid increase of humidity, equal to 2.67 per cent per 100 feet of shaft from the 2,400 to 3,000 foot levels. The humidity below the 2,200 level is constant in winter, practically irrespective of surface conditions. Figure 8 (p. 24) shows average relative humidity readings taken in the same shaft during the months of November, December, January, February, March, and April. At greater depths the rate of increase of humidity becomes greater partly on account of slower air velocity, and partly because the shaft is in somewhat moister ground.

MOISTURE IN SHAFTS AND OTHER WORKINGS—VELOCITY OF AIR AND TEMPERATURE OF ROCK.

Figure 11 (p. 27) shows a rapid increase in the relative humidity of the downcast air in 2,600 feet of comparatively dry timbered shaft on a day when the outside air had a relative humidity of only 34 per cent. The increase was 31 per cent in traveling down 2,600 feet of shaft at a velocity of over 700 feet per minute, or an increase of 1.2 per cent per 100 feet of travel, with a corresponding increase in dry-bulb temperature of 0.66° per 100 feet. After the air reached a humidity of 65 per cent in the shaft, it entered a comparatively dry crosscut with higher rock temperature where its humidity increased at a rate of only 0.22 per cent per 100 feet on account of the rapid increase in dry-bulb temperature (0.96° per 100 feet) and the dryness of the surrounding rock. (See also Fig. 12, p. 28.)

Figures 33 and 34 (pp. 57 and 65) show a relatively slow increase of humidity, when temperatures are rapidly rising; between stations 0 and 5, a distance of 500 feet, as shown in Figure 28, the dry-bulb temperature increased from 58° to $66\frac{1}{2}^{\circ}$ and the relative humidity fell from 65 to 61 per cent; yet at station 5, with a decreased relative humidity of 4 per cent, each 100,000 cubic feet of air passing carried 7.4 gallons of water as against 5.5 gallons at station 0. Air with the lower relative humidity and higher temperature therefore carried the most moisture, because as air is warmed its ability to hold moisture increases at a much faster rate than its temperature.

When the initial temperature of flowing air is low and the relative humidity high, with rock temperature fairly low (Figs. 10, 15, and

19), the increase in the temperature of air is comparatively slow and the relative humidity remains high, as illustrated by Figure 15 (p. 30.) On the other hand, in nearly every air course in Butte mines when the temperature of the air has reached approximately that of the surrounding rock, and the relative humidity is less than 85 per cent, there would be a rapid increase of humidity, especially where the velocity is comparatively slow, less than 500 feet per minute.

Figure 29 shows an increase of 15 per cent relative humidity in air going upward 200 feet through a raise, the entering air having a temperature of $81\frac{1}{2}^{\circ}$, and a relative humidity of 81 per cent, the issuing air having a temperature of 82° and a relative humidity of 96 per cent, the velocity of the air being 50 to 75 feet per minute. Here is an increase of $7\frac{1}{2}$ per cent relative humidity per 100 feet of travel,

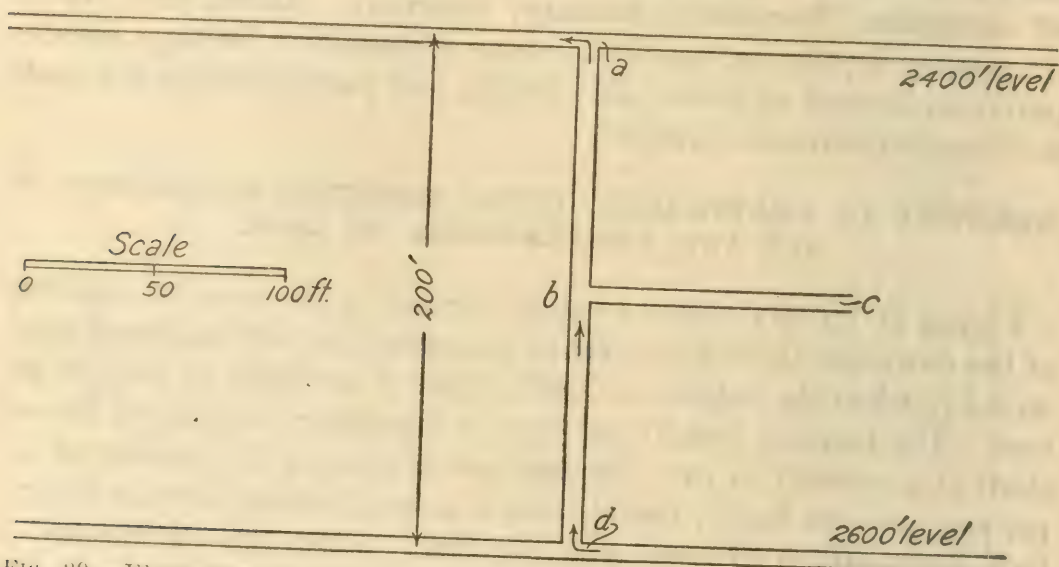


FIG. 29.—Illustration of failure to use available air. Rapid increase of humidity in slow air: *a*, 81° F. wet bulb, 82° F. dry bulb, 96 per cent rel. hum.; *b*, velocity, 50 to 75 ft. a min.; volume, 1,500 cu. ft. a min.; *c*, intermediate breast, rock temperature 87° F., still air 83° F. wet bulb, $84\frac{1}{2}^{\circ}$ F. dry bulb, 94 per cent rel. hum. (very oppressive working place); *d*, 77° F. wet bulb; $81\frac{1}{2}^{\circ}$ F. dry bulb, 81 per cent rel. hum.

which is indicative of the increase in 95 per cent of Butte's working places after one leaves the main air courses with their high air velocities. Out of 246 working faces visited in two large fairly well ventilated mines only 23 had a relative humidity less than 80 per cent, and most of these either were near the surface, were ventilated by small fans and canvas tubing, or had been using large quantities of compressed air in a confined place.

Air that has traveled through several hundred feet of underground workings in Butte mines, especially if those workings are stopes or blind-end faces of drifts and crosscuts, is almost always nearly saturated with moisture. On returning upward to the surface, probably through workings with lower rock temperature, the air cools, becomes supersaturated, and deposits moisture. This tendency is illus-

trated in Figure 13 (p. 28) in which air at 82° F. and 98 per cent relative humidity from lower levels enters a crosscut with an original rock temperature about 73° F.; the air temperature immediately begins to fall and moisture is deposited along the entire length of the crosscut, keeping all timber saturated. The air cooled 3° in traveling 2,000 feet at a velocity of about 200 feet per minute in this crosscut, and then its relative humidity was 100 per cent. A peculiar feature in this crosscut is that although the timbers are saturated continuously with moisture and the air is moving rapidly, decay is so rapid that few if any timbers, though of good pine or fir, last a year before becoming too decayed to support themselves.

Figure 30 shows a decrease in temperature and an increase in the relative humidity of air going from the 2,200-foot level to the collar through a shaft having an electrically driven fan at the surface. Figure 31 gives similar data for an upcast shaft without a fan, both shafts belonging to the same mine. The velocity of the fan-actuated current is about 500 feet per minute as against 150 feet per minute for the natural upcast; the velocity of the latter is impeded also by cages and skips, whereas the fan shaft is not used for hoisting.

It is noteworthy that the air temperature at the collar of each shaft was about 73° F. and the relative humidity 100 per cent, but the air entered the foot of the shaft at 71°, rapidly warmed to 85°, and then cooled to 73° at the surface, whereas the air entered the foot of the other shaft at 82°, or 11° higher. In

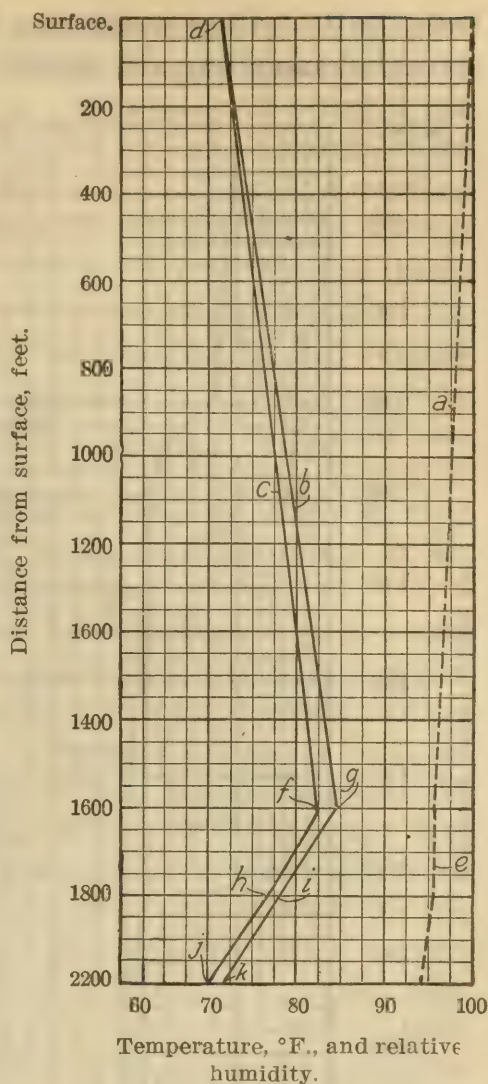


FIG. 30.—Temperature and humidity of the return air in a shaft having a suction fan: *a*, Rel. hum.; *b*, dry bulb; *c*, wet bulb; *d*, return air as discharged to surface, 71½° F. both wet and dry bulb, 100 per cent rel. hum., volume 33,000 cu. ft. a min., outside air 33½° F., 53 per cent rel. hum.; *e*, this shaft has a suction fan on the surface, velocity in shaft approximately 500 ft. a min.; *f*, air into shaft from 1,800-ft. level 84° F., 96 per cent rel. hum., volume 14,000 cu. ft. a min.; *g*, falling water in shaft, 79° F.; *h*, air into shaft from 2,000-ft. level, 78° F., 96 per cent rel. hum., volume 12,500 cu. ft. a min.; *i*, falling water in shaft 77½° F.; *j*, air from 2,203 "B" drift to shaft, 71° F., 94 per cent rel. hum., volume, 5,000 cu. ft. a min.; *k*, falling water in shaft 71° F.

both shafts falling water, due to the condensation of the moisture-saturated ascending air, greatly impeded the flow of air, a condition

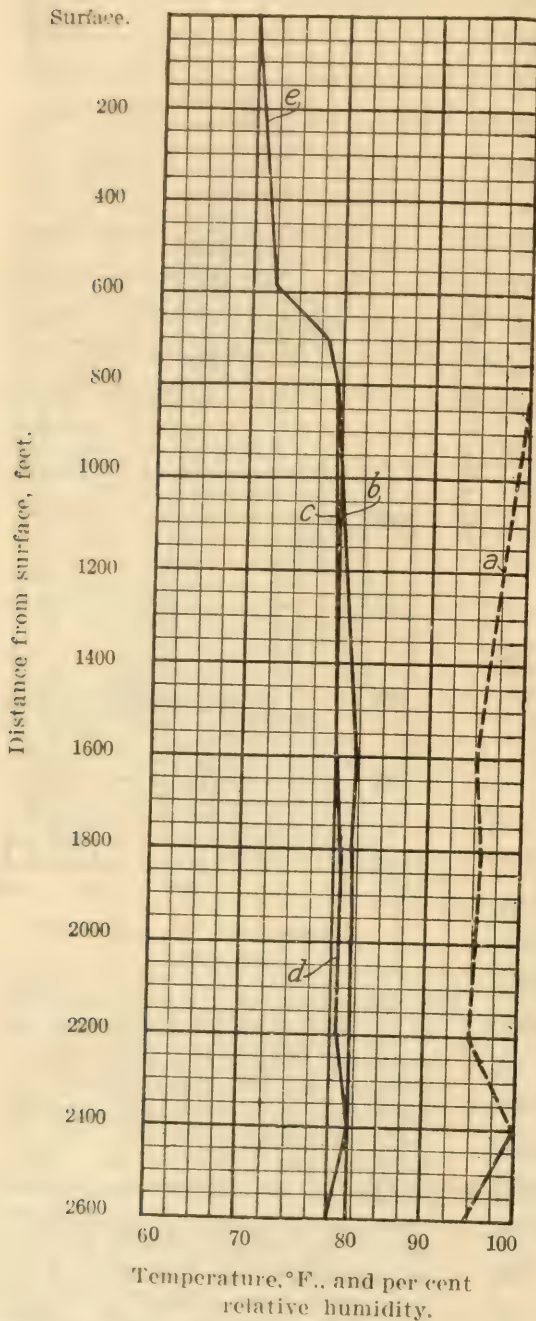


FIG. 31.—Temperature and humidity of the return air in a shaft with natural ventilation: *a*, Relative humidity; *b*, dry bulb; *c*, wet bulb; *d*, this shaft is natural upcast, velocity 150 ft. a min.; *e*, temperature of return air as discharged at surface, 71° F. wet and dry bulb, 100 per cent rel. hum.; outside air 29° F., volume approximately 10,000 cu. ft. a min.

temperature, with a corresponding decrease of relative humidity. To these changes much of the merit of this method of ventilation is due.

typical of upcast shafts at Butte. In the shaft with the fan, the air at the 1,800 station, with a temperature of 85° and a relative humidity of 96 per cent, carried 21 gallons of water per 100,000 cubic feet; at the surface, with 73° temperature and 100 per cent relative humidity, the air contained only 15 gallons per 100,000 cubic feet, hence it lost 6 gallons per 100,000 cubic feet in traveling 1,800 feet to the surface. The total volume was 33,000 cubic feet per minute, or 47,520,000 cubic feet per 24-hour day, which means that nearly 2,900 gallons per 24 hours fell down the shaft against the ascending air and tended to reverse the current. Similarly, in the shaft having natural ventilation, and hence very little "draft" at certain times of the year, about 700 gallons of water condensed and fell back each 24 hours. On some days this falling water actually converted the shaft from upcast to downcast.

USE OF SMALL CANVAS AND GALVANIZED IRON TUBING.

When mine air is forced through dry galvanized iron or canvas tubing at velocities of 2,000 to 6,000 linear feet or more per minute, there is generally a rapid increase of tem-

Figure 16 (p. 31) shows a decrease of 15 per cent in the relative humidity of the air forced 300 feet through 10-inch canvas pipe at a velocity of 4,800 linear feet per minute, a decrease of 5 per cent per 100 feet of travel in the pipe. Figure 16 shows also a quick increase of humidity after leaving the canvas pipe, even in a rapidly moving current; there were some roof drippers at the end of the canvas pipe, and the fast-moving air went about 15 feet through these drippers, increasing in humidity from 71 per cent at the end of the canvas pipe to 96 per cent after issuing from the drippers, but quickly dropping again to 91 per cent at the face, due to the rapid rise in the temperature of the air in mixing with the surrounding air and in encountering rock with a temperature of 91° . Figures 17 and 18 also illustrate the rapid decrease of relative humidity in air flowing through canvas tubing and the rapid increase of humidity in air going through drippers after leaving the tubing.

Figure 22 (p. 41) represents readings of the air in an 8-inch canvas pipe, and shows the rapid decrease of relative humidity with increase of temperature; Figure 23 gives similar data for 16-inch canvas tubing. Figure 24 shows a rapid rise in temperature and a decrease in relative humidity in a short length of 16-inch galvanized-iron tubing having two 45° elbows, the velocity being over 6,000 linear feet per minute; Figure 25 gives similar readings for a short length of 16-inch canvas tubing with two 45° and one 90° galvanized elbows, and an air velocity of 6,700 linear feet per minute. With a temperature increase in the dry galvanized pipe of $11\frac{3}{8}^{\circ}$ F. per 100 feet, humidity decreased $31\frac{3}{8}$ per cent per 100 feet, whereas with a temperature increase of $5\frac{1}{4}^{\circ}$ per 100 feet in the dry canvas tube relative humidity fell 13.7 per cent per 100 feet. When, however, about 12 gallons of water per hour at 67° F. was introduced as a spray into the fan intake supplying the 16-inch canvas pipe, as indicated by *d*, Figure 25, and also by the tabulation taken from the same figure, the dry-bulb temperature of the air discharge was no higher than that of the intake air, and the relative humidity increased about 7 per cent per 100 feet of travel in the pipe.

Several examples have been given above, and many others could be cited that show a rapid increase of temperature and a decrease of relative humidity in air forced through dry galvanized iron or canvas pipe; under some mining conditions, however, air actually loses temperature and gains humidity in flowing through canvas tubing. Figure 26 (p. 44) shows practically saturated (98 per cent) return air at a comparatively high temperature (82°) flowing 2,200 feet through 16-inch canvas tubing at a velocity of 4,200 feet per minute at the discharge end; the discharged air had a temperature of 79° F., a decrease of 3° F., and a relative humidity of 100 per cent, an increase of 2 per cent.

A probable reason for this result is the numerous long lengths of crosscut in which "drippers" at a temperature of 72° to 75° F. fall on the canvas pipe saturating it and cooling it to their temperature; moreover, the original rock temperature of the crosscut was about $72\frac{1}{2}^{\circ}$ or 73° F. The entering air, temperature at 82° F., relative humidity, 98 per cent, carried about $19\frac{1}{2}$ gallons of water per 100,000 cubic feet, but the discharge air carried only $18\frac{1}{2}$ gallons per 100,000 cubic feet; hence there was deposited in the 2,200 linear feet of canvas pipe about 1 gallon of water per 100,000 cubic feet of air passing, or

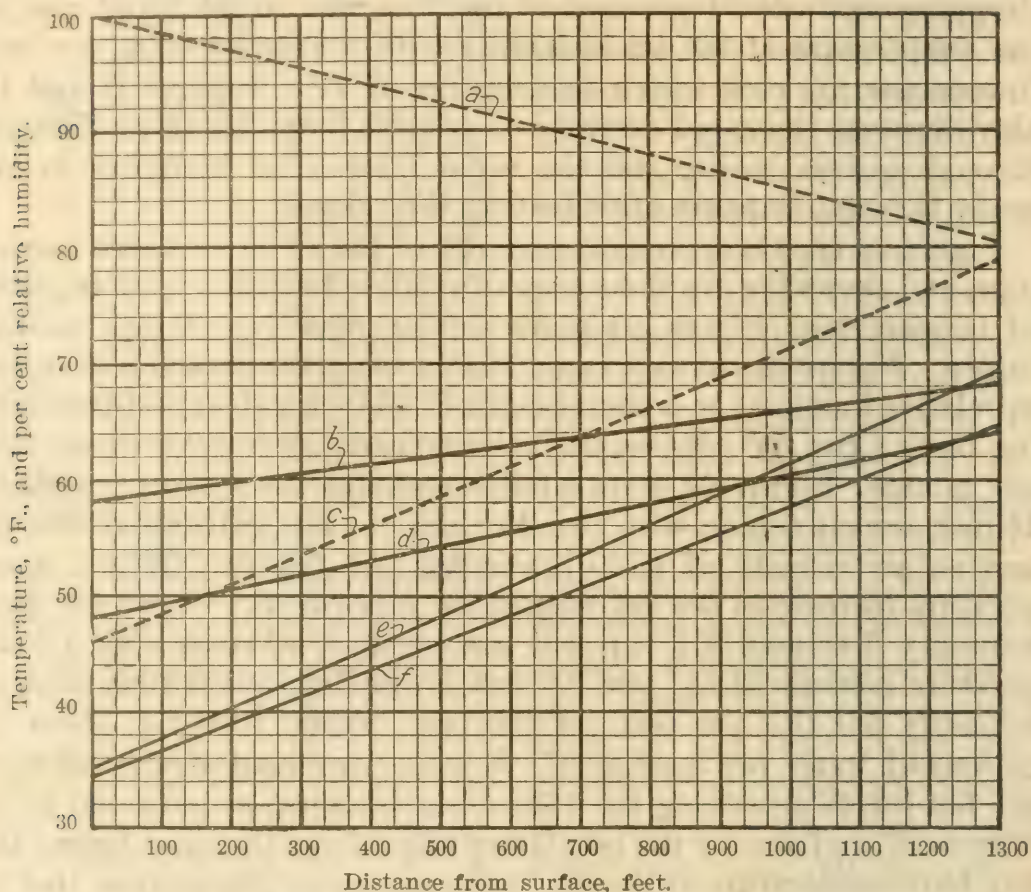


FIG. 32.—Practically constant temperature and relative humidity during summer at the 1,300-ft. station of a downcast shaft with widely divergent surface temperatures and humidity; 10 minutes or less elapsed between time of taking surface and underground readings: *a*, Relative humidity, June 21, 1916, from 12.25 to 12.30 p. m.; *b*, dry bulb, June 23, 1916, from 11.50 a. m. to 12 m.; *c*, relative humidity, June 23, 1916, from 11.50 a. m. to 12 m.; *d*, wet bulb, June 23, 1916, from 11.50 a. m. to 12 m.; *e*, dry bulb, June 21, 1916, from 12.25 to 12.30 p. m.; *f*, wet bulb, June 21, 1916, from 12.25 to 12.30 p. m.

about 3.3 gallons per hour. To continue effective use of the tubing, eyelets and corks had to be placed in the bottom, the eyelets being opened at intervals to let out the water.

Before the fan and canvas pipe were installed there was much difficulty in holding men to drive this crosscut, which was nearly one-half mile from the circulating air. After the fan and canvas pipe were in operation, conveying about 5,500 cubic feet of swiftly moving air to the face, not only were men easily obtained and held,

but much faster progress was made, and the cost of the work was reduced almost 50 per cent. The air issuing from the end of the canvas pipe was saturated with moisture and had a temperature of 79° F.

USE OF WATER.

The principle of using cool water to reduce air temperatures, even at a possible increase of humidity, should be applied much more frequently in metal mining than it has been. Figure 25, show-

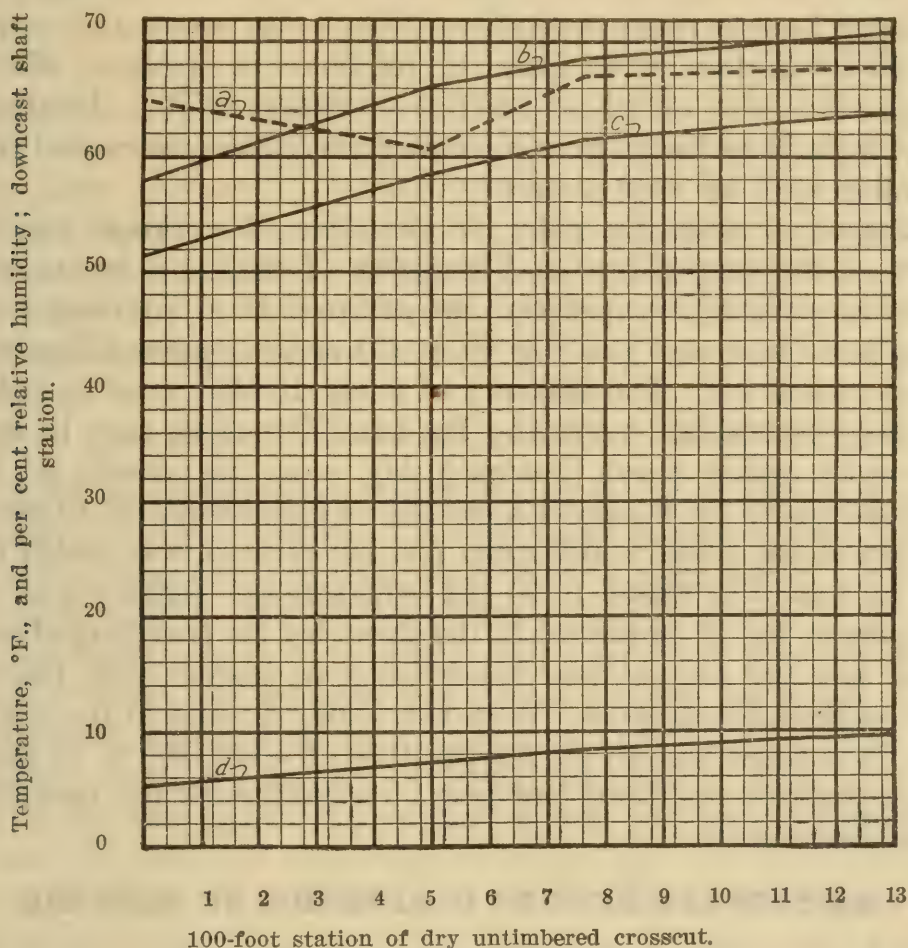


FIG. 33.—Changes of temperature and humidity in air flowing through a dry untimbered crosscut: *a*, Relative humidity; *b*, dry bulb; *c*, wet bulb; *d*, gallons of water to 100,000 cu. ft. of air. Decrease in humidity surface to 500-ft. station with increase of water carried per 100,000 cu. ft. of air. Average increase of relative humidity, 0.22 per cent in 100 ft. of crosscut (1,300 ft.). Average increase in 100 ft. of comparatively dry crosscut of gallons of water to 100,000 cu. ft. of air, 0.27.

ing the use of a water spray, and Figure 26, showing the effect of comparatively cool drippers, indicate what can be accomplished. A Bureau of Mines engineer and some of the mining operators of the Comstock district in Nevada were able to reduce the temperature of the air in one of the Comstock drifts from 104° F. to less than 99° F., or 5° in 7 minutes, by using four water sprays with very poor pressure in 140 feet of drift, the air velocity in which was 240 linear feet per minute. The temperature of the water, which had been piped

from the surface to the 2,500-foot level, where the experiment was made, was 50° F. The engineer expressed the opinion that with adequate pressure and proper arrangement of the four sprays the air temperature could have been reduced 15°.

The temperature of Butte city water even in midsummer is as low as 65° F. after being piped over 2,500 feet vertically underground. The water in the spray experiment (Fig. 25) had a temperature of 67° F. on the 2,600-foot level, though it had stood for hours in a steel tank in a drift with the rock temperature over 80° F. The city water used for Leyner drills was taken from tanks containing approximately 200 gallons; after standing for hours in crosscuts with rock temperature over 100° F. it had a temperature of 75°. Evidently it is not difficult in Butte, even in summer, to obtain water cool enough to reduce high air temperatures.

Running or standing water on the floor of workings has slight effect on the temperature and humidity of mine air, but maximum results in reducing temperature are attained in a minimum time by using water in sprays (see Fig. 25, p. 43) or in drippers (Figs. 16 and 17, pp. 31 and 32). The efficiency of finely divided water in reducing the temperature and increasing the humidity of air may be seen in Figure 15, which shows that on a day when the outside air had a temperature of 79° F., and a humidity of approximately 10 per cent, the intake air, about 13,000 cubic feet per minute, was cooled to 51° and its humidity raised to 93 per cent through contact with water drippers at 48° F. in the shaft, the downcast air traveling about 250 linear feet per minute, and hence being in contact with the water for less than five minutes. With this water flowing in the shaft the mine in summer had an air temperature of about 50° F. at the foot of the shaft on the 1,200-foot level, irrespective of the temperature of the surface air.

FACTORS INFLUENCING COMPOSITION OF MINE AIR.

COMPOSITION OF OUTSIDE AIR.

Pure, dry outside air, as shown by analyses of samples taken in Butte and at various places throughout the world, consists of about 20.93 per cent oxygen, 0.03 per cent CO₂, and 79.04 per cent of various other gases, all in negligible proportions except nitrogen. In the past the smelters at Butte impregnated the surrounding atmosphere with gases containing sulphur and arsenic, which prevented the growth of vegetation. At present most of the Butte ore is smelted at Anaconda, 28 miles distant, and only one smelter remains in Butte; so that the city air is almost normal and vegetation prospers. Nevertheless, during the winter dense fogs and mists are frequent, especially in the lower parts of the district, and they may contain harmful gases.

In a dense fog on a day late in November, 1917, in front of the Montana School of Mines, the writer took samples of outside air which on analysis by Bureau of Mines chemists at Pittsburgh, Pa., had the following composition:

Analysis of outside air during a fog.

	Per cent.
O ₂ -----	20.88
CO ₂ -----	0.06
CH ₄ -----	0.00
N ₂ -----	79.04
SO ₂ -----	0.02

The percentage of CO₂ is slightly above normal and 0.02 per cent of SO₂ must be considered high. Though these fogs are frequent in the lower part of the town, only occasionally do they reach the vicinity of most of the mine shafts. During mine fires, however, especially in winter, fire gases issuing from one shaft have been known to hang close to the ground in low places and to travel to adjacent down-cast shafts, causing annoyance, though possibly no immediate physical danger.³

BREATHING OF MEN AND ANIMALS.

Without doubt the breathing of human beings, horses, and mules depletes the oxygen content of mine air and increases the CO₂ content, and consequently must be important in very poorly ventilated or confined places. Table 7 shows the average analyses of air samples from such places in a fairly well ventilated Butte mine; in breasts of drifts and crosscuts the oxygen content (20.93 per cent at the surface) declined to 20.19 per cent and the CO₂ from 0.03 at surface increased to 0.42 per cent; in raises oxygen decreased to 20.54 per cent and CO₂ increased to 0.22 per cent. These workings were all new and advancing, consequently there would be little or no oxidation of timber and most of the increase of CO₂ and the decrease of oxygen were due to the breathing of men (there were no horses) and to mine lights. The depletion of oxygen and the increase in CO₂ from new working stopes with poor ventilation was less than in either raises or drift and crosscut faces, probably on account of the greater volume of open ground in stopes; where the stopes were in old gob, and had decaying timber, the oxygen depletion of air was excessive and the CO₂ content high.

Though these considerations hold for confined places, yet the depletion of oxygen and the increase of CO₂ in the main return air currents of Butte mines can not be wholly accounted for by the breathing of men and animals and the use of lights. In a fairly well ven-

³ For the physiological effects of smoky atmosphere, see Smoke investigations; Mellon Institute Industrial Research and School of Specific Industries Bull. 9, pp. 50-55.

tilated mine in Butte, as Table 7 shows, the total quantity of air circulated was 51,200 cubic feet per minute or 3,072,000 cubic feet per hour, the oxygen content of the return air was 20.20 per cent, a depletion of 0.73 per cent or 22,425 cubic feet per hour. The maximum working force comprised about 450 men, each of whom, according to physiologists, should consume, when working fairly hard, about 1.1 cubic feet per man per hour or about 495 cubic feet per hour of oxygen consumption for the entire force; if the oxygen consumption of their small carbide lamps should be placed at an equal quantity, the total would be less than 1,000 cubic feet per hour or less than 5 per cent of the total oxygen depletion in the mine.

Similar considerations apply to the increase of CO_2 . Table 7 shows that CO_2 increases from 0.03 per cent in surface air to $0.30\frac{1}{2}$ per cent in the average return air, an increase of $0.27\frac{1}{2}$ per cent, or of 8,450 cubic feet per hour. Again assuming that 1.1 cubic feet of oxygen was consumed per hour per man in breathing, the CO_2 exhaled corresponding to this amount of oxygen consumed would be 1.5 cubic feet per hour; this amount is probably much above the normal production of CO_2 in breathing, which is 0.7 to 0.8 cubic foot per man per hour; for 450 men the total CO_2 produced by their breathing would be 675 cubic feet per hour. If we add an equal amount, which would be excessive, for the effect of miners' lights, the total from human breathing and from lights would be only 1,350 cubic feet of CO_2 per hour, or about 15 per cent of the mine's hourly production of 8,450 cubic feet. Hence in this fairly well ventilated Butte mine the breathing of animals and the effect of miners' lights account for less than 5 per cent of the oxygen depletion and for less than 17 per cent of the CO_2 increase.

Table 9 gives data on a poorly ventilated Butte mine having a small total quantity of air, 15,500 cubic feet per minute, circulating at slow velocities. The CO_2 content increases 0.42 per cent and the oxygen decreases 1.29 per cent with 300 men employed and 930,000 cubic feet of air supplied per hour. This figure gives 12,000 cubic feet of oxygen depletion per hour, of which a maximum of 660 cubic feet per hour is chargeable to the breathing of animals and the use of lights, or less than 6 per cent; with an increase of 3,906 cubic feet of CO_2 per hour, only 900 cubic feet per hour, or about 23 per cent, could be ascribed to breathing and lights. In the poorly ventilated mine, then, less than 6 per cent of oxygen absorption and about 23 per cent of increased CO_2 can be charged to human breathing and lights, which indicates that defective ventilation apparently increases oxidation of timber, and most of the oxygen lost underground, whether in good or poor ventilation, is absorbed without yielding proportionate quantities of CO_2 .

TABLE 8.—Analyses of air in mine B, which has an old mine fire and uses force fans at downcast shafts.

Place.	Wet bulb, °F.	Dry bulb, °F.	Relative humidity, per cent.	CO ₂	O ₂	CO	CH ₄	N ₂	Velocity, feet per minute.	Quantity.	Remarks.
Main return.	82	87	80	0.27	20.14	0.00	0.00	79.59	400	27,000	Much air from fire area.
Do.				0.27	20.18	0.00	0.00	79.55	400	30,000	Do.
Averages.				0.27	20.16	0.00	0.00	79.57		57,000	Total return for mine with 350 men underground per shift.
Outside air.				0.03	20.93	0.00	0.00	79.04			
<i>Stopes.</i>											
900, fifth floor M. vein.	87	108	44	0.19	20.48	0.00	0.00	79.35	None.		Very oppressive place; near fire.
800, eighth floor M. vein.	77	85	70	0.25	20.31	0.00	0.00	79.44	do.		Reclaimed fire area; timber gas.
800, seventh floor M. vein.	77	85	70	0.26	20.18	0.00	0.00	79.56	do.		Do.
700, S. vein.				0.37	19.29	0.00	0.00	80.34	do.		Cool; abandoned fire area; timber gas.
500, third floor M. vein.	82	91	68	0.08	20.76	0.00	0.00	79.16	do.		Very oppressive.
<i>Drifts and crosscuts.</i>											
2,202 M. crosscut.	82	84	92	0.25	20.33	0.00	0.00	79.42	None.		Breast. Men claimed headache.
1,432 M. crosscut.	130	430+	(?)	1.40	14.70	0.00	Tr.	83.90	(?)	(?)	Leak from fire zone.
927 M. crosscut.	94	95	96	2.49	13.38	0.08	0.00	84.05	(?)	(?)	Do.
949 M. crosscut.	75	92	44	0.58	19.26	0.00	0.00	80.16	None.		Taken outside fire bulkhead 5,200.
400 M. crosscut.	72	77	78	0.18	20.16	0.00	0.00	79.66	130		Main split between veins.
<i>Raises.</i>											
2,159 M. vein.	81½	82½	96	0.61	18.66	0.00	0.00	80.73	None.		Taken 90 feet up a 170-foot raise; candle would not burn above.
900 M. vein.	91	108	51	0.26	20.41	0.00	0.00	79.33	do.		Very uncomfortable place.

NOTE.—Air samples at working face were taken only when some unusual condition was encountered or suspected.

TABLE 9.—*Analyses of air from mine C, having comparatively shallow workings and using natural ventilation.*

Place	Wet bulb, °F.	Dry bulb, °F.	Relative humidity, per cent.	CO ₂	O ₂	CO	CH ₄	N ₂	Velocity, feet per minute	Volume, cubic feet per minute.	Remarks.
Main return	76	76½	97	0.47	19.51	0.00	0.00	79.92	200	13,500	Total return for mine with about 300 men underground.
Main intake	51	74		0.05	20.90	0.00	0.00	79.05	270	13,500	Compressed exhaust from pump.
Outside air (theoretical)				0.03	20.93	0.00	0.00	79.04	(7)		
Compressed air (1,500)	49	57	62	0.09	20.80	0.00	0.00	79.11			
<i>Stopes.</i>											
830, twelfth floor	85	88	92	0.95	18.11	0.00	0.00	80.94	None		Very poor air in working stoppe.
700, seventh floor	96½	100	100	0.09	20.45	0.00	0.00	79.46	do.		O ₂ depletion but not much CO ₂ .
700, seventh floor	100	100	100	0.73	16.87	0.00	0.00	82.40	do.		Same place, year later.
1,565, fourth floor	84	85	96	0.47	20.03	0.00	0.00	79.50	do.		Uncomfortable place.
1,547, eighteenth floor	81	81½	97	0.74	19.48	0.00	0.00	79.73	do.		At times candle would not burn.
<i>Lands.</i>											
1,500 near upcast	79½	80½	96	0.23	20.48	0.00	0.00	79.29	50	1,300	Main return 1,500-foot.
1,200 near upcast	76	76½	97	0.22	20.30	0.00	0.00	79.48	85	3,000	Main return 1,200-foot.
1,000 near upcast	76	76½	97	0.74	18.48	0.00	0.00	80.78	30	700	Main return 1,000-foot.
800 near upcast	77	78½	96	0.22	20.52	0.00	0.00	79.26	190	6,700	Main return 800-foot.
800 near upcast	79½	81	95	0.90	18.08	0.00	0.00	81.04	120	3,840	Same as preceding, but a year later.

NOTE.—Air samples at stope faces were taken only when conditions seemed unusual. This mine is not connected to any other mine. Data were taken in summer when ventilation conditions are worst.

TABLE 10.—Analyses of mine air of mine D, having practically dead mine fire and having exhaust fan ventilation.

Place.	Wet bulb, °F.	Dry bulb, °F.	Relative humidity, per cent.	CO ₂	O ₂	CO	CH ₄	N ₂	Velocity.	Volume.	Remarks.
Main return				0.21	20.30	0.00	0.00	79.48	(?)	(?)	Main return for mine with 400 men underground per shift.
Outside air	42 (?)	54 (?)	52	0.03	20.93	0.00	0.00	79.04	(?)	(?)	Temperature and humidity are average of 22 readings, June, 1916.
<i>Stopes.</i>											
1,402, ninth floor	75	77	91	0.32	20.50	0.00	0.00	79.68	None		Men complained of headache; no shooting.
1,800, fifth floor	70½	75	80	0.20	20.62	0.05	0.00	79.13	Slight	(?)	Fired two shots; men complained of headache.
<i>Raisers.</i>											
502, fifth floor	78	79½	93	0.38	20.27	0.00	0.00	79.38	None		An oppressive place.
1,370, ninth floor	72	73	95	0.20	20.54	0.00	0.00	79.26	do		Oppressive, but not hot.
<i>Drifts and crosscuts.</i>											
1,155											"Sweet gas," miners have headaches.
1,000, fire level	70	73	86	0.31	20.45	0.00	0.00	79.24			Fire sealed area; candles burning when held still, but goes out when moved.
1,004, fire level	96	101	100	1.04	17.31	0.00	0.00	81.05	None	(?)	Gas from practically dead fire.
		98	93	0.39	20.13	0.00	0.00	79.48	do	(?)	

TABLE 11.—Analysis of so-called timber gas from Butte mines.

Place.	Wet bulb, ° F.	Dry bulb, ° F.	Relative humidity, per cent.	CO ₂	O ₂	CH ₄	CO	H ₂	Velocity.	Volume, cubic feet per minute.	Mine.	Remark.
1, 1st slope, ninth floor.	75	77	91	0.32	20.60	0.00	0.00	79.68	None.	.....	D	Working slope, no bleeding, men have headache.
2, 2nd slope, eighth floor.	80 1/2	80 1/2	96	0.61	18.96	0.00	0.00	80.73	do.	.....	B	Sample taken, 90 feet up a 176-foot raise, candle is this guttered; candle extinguished higher up, not worked for months, timbered.
300 slope, eighth floor.	77	85	70	0.25	20.31	0.00	0.00	79.44	do.	.....	B	Timber gas, reclaimed fire slope.
300 slope, seventh floor.	77	85	70	0.25	20.18	0.00	0.00	79.55	do.	.....	B	do.
700 level.	77 1/2	77 1/2	100	0.37	19.29	0.00	0.00	80.44	do.	.....	B	Timber gas from abandoned slope.
1, 304 drift, tenth floor.	82	82 1/2	94	0.25	20.35	0.00	0.00	79.72	30 feet p. m.	1,000	A	From abandoned slope.
1, 307 slope, third floor.	78	80	92	0.15	20.65	0.00	0.00	79.19	Slight	.....	A	From abandoned slopes.
2, 307 drift, sixth floor.	81 1/2	83	93	0.36	20.05	0.00	0.00	79.53	None	.....	A	Resampling work in abandoned raise, very oppressive, head ache and excessive perspiring, even when men not working.
2, 303 crosscut.	80	80	100	1.51	18.28	0.00	0.00	79.84	do.	.....	A	100 feet from breast, candle barely burns, not worked for months.
1, 675 1/2 crosscut.	82	82	100	0.45	20.12	0.00	0.00	79.43	180	4,000	A	Much fungus, old slopes.
1, 675 1/2 crosscut.	86	90	85	0.46	20.11	0.00	0.00	79.40	None	.....	A	No fungus, old slopes, candle like fine area.
632 drift breast.	64 1/2	65	92	0.32	19.41	0.00	0.00	79.68	do.	.....	A	In old gobs, much decayed timber, resampling old ground, men complain of headache.
457 slope, sixth floor.	73	74	95	0.45	20.15	0.00	0.00	79.40	do.	.....	A	In old gobs, no bleeding here, men complain of headache.
426 slope, fifth floor.	74	75	95	0.55	19.80	0.00	0.00	79.65	do.	.....	A	In old gobs, when old timber encountered much "gas" makes men sleepy.
2, 203 drift breast.	78 1/2	79	86	0.45	20.27	0.00	0.00	79.18	do.	.....	A	Breast of drift in solid ore, men had not worked for 10 days, very wet and heavily timbered.
452 slope, sixth floor.	73	74	95	0.46	19.94	0.00	0.00	79.60	do.	.....	A	In old gobs, men complain of headache.
2, 079 crosscut.	79	79	100	0.30	20.75	0.00	0.00	79.45	600	15,000	A	Between 40, much fungus, timber decays to less than one year here. In solid crosscut where air still and temperature 79° F. and humidity 7.94 per cent, no fungus and not much decay of timber.
Average.				0.44	19.90			79.65				

OXIDATION OR ABSORPTION OF OXYGEN BY TIMBER AND ORE.

As indicated above, the main cause of the depletion of oxygen and the increase of CO_2 in mine air is not the breathing of animals or the

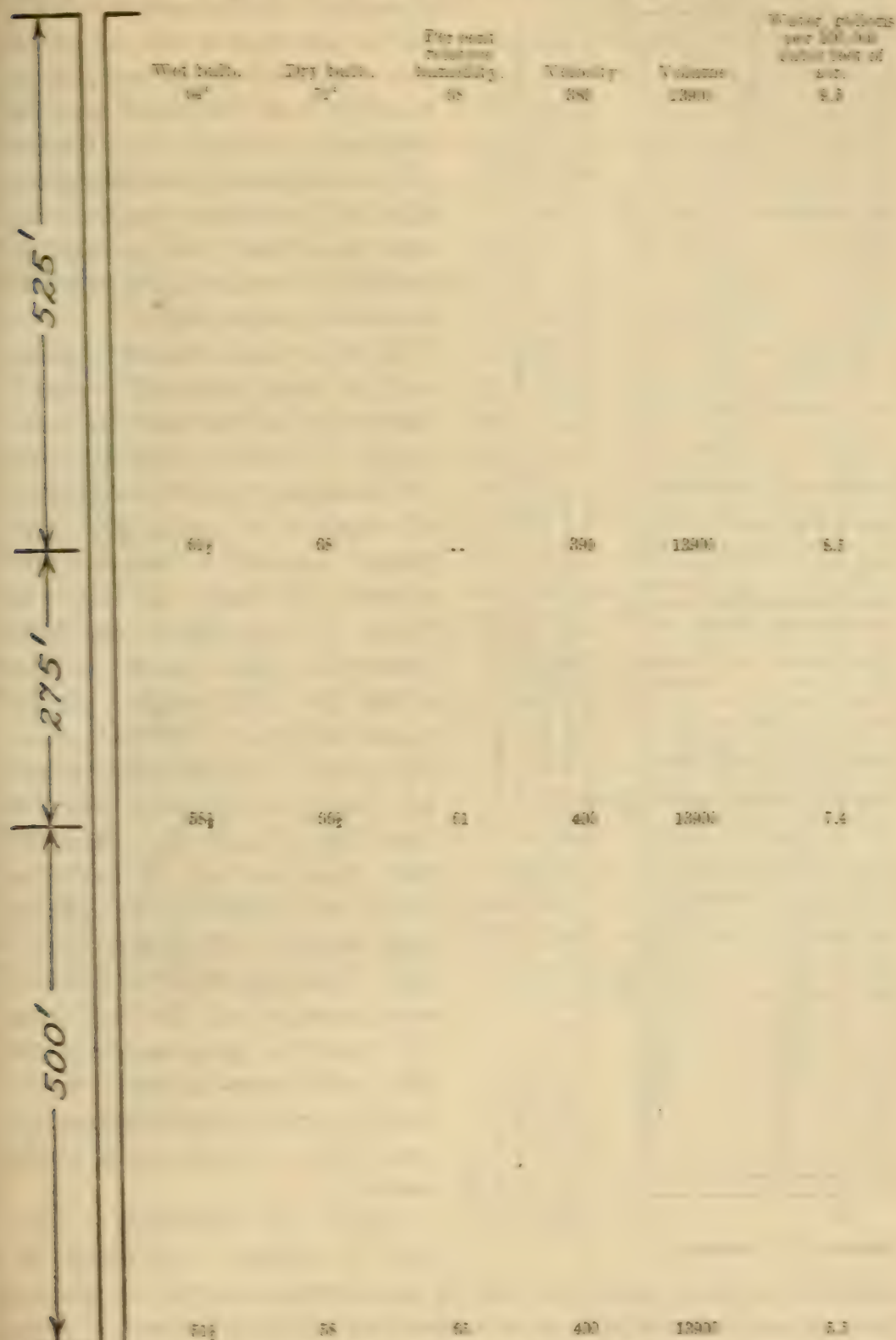


FIG. 34.—Progress of temperature and humidity in 1,500 feet of dry unmineralized crosscut.

use of open lights. The miner knows the main cause of this vitiation of air when he speaks of "timber gas." Table 11 gives analyses of

samples taken in so-called timber gas. The men claimed that the timber gas caused headache even when temperatures were below 75° F. and the relative humidity less than 95 per cent. The cause, ap-

parently, was the increase of CO_2 to 0.5 per cent or the 0.7 to 1.5 per cent decrease of oxygen, or possibly both combined, and the stagnation of the air. Timber gas was especially bad in regions that had previously been worked and abandoned, and in the reworking of which decaying timber was encountered.

In blind ends of drifts, crosscuts, or raises, timbered or partly timbered, not worked for some weeks or months, and deprived of circulating air, the depletion of oxygen is practically complete, especially where the ground is damp or wet. In Table 11, a sample in the 2,059 raise was taken about 90 feet above the drift where a candle would not burn; 20 feet above this point a carbide lamp would not burn, yet the raise was 170 feet high; hence for about 80 feet from the top of the raise there was probably an almost total depletion of oxygen. Similarly, a sample in 2,801 crosscut was taken about 700 feet from the face of a blind-end crosscut at a point where a candle would barely burn; a short distance beyond this a carbide lamp would not burn.

Figure 35 illustrates a system of natural ventilation es-

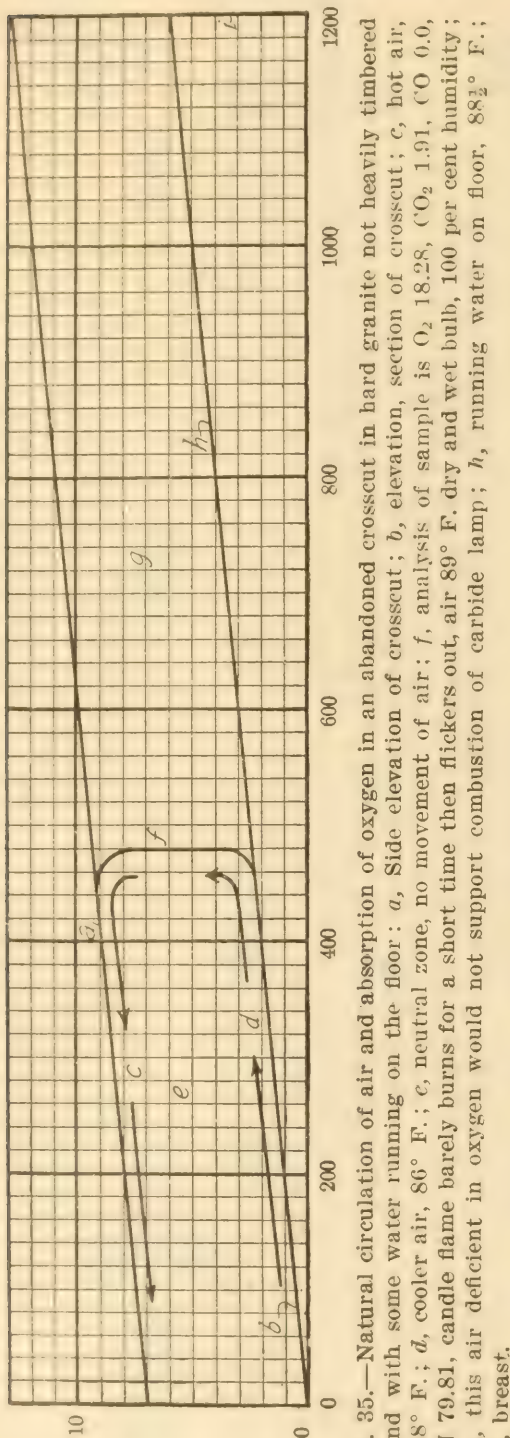


FIG. 35.—Natural circulation of air and absorption of oxygen in an abandoned crosscut in hard granite not heavily timbered and with some water running on the floor: *a*, side elevation of crosscut; *b*, elevation, section of crosscut; *c*, hot air, 88° F.; *d*, cooler air, 86° F.; *e*, neutral zone, no movement of air; *f*, analysis of sample is O_2 18.28, CO_2 1.91, CO 0.0, N 79.81, candle flame barely burns for a short time then flickers out, air 89° F. dry and wet bulb, 100 per cent humidity; *g*, this air deficient in oxygen would not support combustion of carbide lamp; *h*, running water on floor, 88½° F.; *i*, breast.

tablished in this crosscut; the line of demarcation between circulating pure air and vitiated still air was like a wall in its definiteness; along the floor cool dry air went toward the face of the crosscut for about 500 feet, then turned up toward the roof or back, and mixing with a little of the warmer saturated air went out again. The saturated

air stream near the roof caused the timbers to be moistened from the roof to about 2 to $2\frac{1}{2}$ feet below, thence the timbers were dry nearly to the floor, on which was a small stream of running water.

The sample in 2,079 crosseut, Table 11, strictly speaking, was not timber gas, but was return air from long opened, timbered workings several hundred feet deeper; it caused a very rapid decay of timber for more than 2,000 feet of crosscut in granite. The air entered the crosscut at 82° F. and 98 per cent relative humidity, and on encountering cool rock dropped to 79° F. and 100 per cent relative humidity, depositing so much moisture that the timber was kept continually saturated. The growth of fungus was luxuriant and sound pine and fir timber decayed completely in less than a year and had to be replaced. Fungus was abundant and the decay of timber rapid in the 1,675 north crosscut also (the air sample in Table 11), the air at 82° F. and 100 per cent relative humidity moving from old stopes at a rate of about 180 feet per minute, kept the timbers moist; on the other hand, a few hundred feet distant, stagnant air from old stopes at 90° F. and 85 per cent relative humidity did not seem to cause timber decay and no fungus could be seen. Samples of air taken in these two places showed almost the same oxygen depletion and increase of CO_2 , yet in one place the decay of timber was rapid and in the other was not marked. Air of high humidity seems conducive to the decay of timber, irrespective of temperature, and the decay may be fully as rapid in moving as in stagnant air.

The depletion of oxygen is much in excess of the formation of CO_2 ; the average depletion of oxygen in 18 samples of timber gas in Table 11 is 1.03 per cent, and the CO_2 proportional to that would be 1.41 per cent, but the actual average found was only 0.44 per cent. It seems that of the 1.03 per cent of oxygen depletion shown by the average of the 18 samples of timber gas, only 0.32 per cent is utilized in the formation of CO_2 , leaving about 0.71 per cent to be disposed of otherwise, probably through absorption by timber.

TABLE 12.—*Analyses of samples of gases from Butte mine fires.*

Place.	Wet bulb, °F.	Dry bulb, °F.	Relative humidity, per cent.	CO ₂	O ₂	CO	CH ₄	N ₂	H ₂	Total.	SO ₂	Mine.	No.	Remarks.
Surface, main return.				1.45	18.80	0.20	Tr.	79.45	0.10	100	.....	E.	1	New fire in back-filled slope.
1,200, in old gob.				0.25	20.50	0.05	.....	79.20	0.10	100	.....	E.	2	Do.
1,000, in old gob.				4.82	14.58	0.68	0.44	79.09	0.39	100	.....	E.	3	Same as above; sweet gas.
Surface, return.				0.31	20.50	0.07	.....	79.12	.....	100	.....	A.	4	Return from shaft fire four days after start; fan at top of burning shaft.
Do.				0.32	20.53	0.08	.....	79.07	.....	100	.....	A.	5	Exhaust from another shaft, same mine; quantity 3,200 feet per minute.
Do.				0.29	20.44	0.04	.....	79.23	.....	100	.....	A.	6	New fire; extension of old fire.
1,413 drift.				1.26	19.60	0.07	0.34	78.73	.....	100	Tr.	F.	7	Close to new fire.
1,308 drift.	96½	96½	100	5.40	14.43	1.17	0.95	77.93	.....	100	0.12	F.	8	Taken by man wearing breathing apparatus; dense smoke.
1,427 slope 20th floor.	96½	96½	100	3.10	16.89	0.23	0.30	79.44	.....	100	0.04	F.	9	125,000 cubic feet per minute from above fire region.
1,401 drift.	130+	130+	(?)	4.45	16.65	0.38	1.32	77.04	.....	100	0.16	F.	10	Same as above but 3 days later.
Surface, main return.	88	88	100	2.45	17.70	0.30	0.23	79.28	.....	100	0.04	F.	11	Same as above but 4 months later.
Do.	89	89	100	2.32	17.97	0.29	0.18	79.18	.....	100	0.06	F.	12	Taken from pipe in bulkhead.
Do.				0.84	19.15	0.00	0.00	80.00	.....	100	0.01	F.	13	Duplicate of above.
1,300 winze.				0.69	19.45	0.00	0.00	79.70	.....	100	0.16	F.	14	Sample from diamond drill hole to fire.
1,206 fire bulkhead.	125+	125+	(?)	18.11	0.30	2.09	2.90	76.60	0.00	100	.....	F.	15	Taken 2 months after start of fire.
Do.	125+	125+	(?)	18.29	0.25	1.76	3.19	76.51	0.00	100	.....	F.	16	Taken 7 months after start of fire; fire about extinguished.
Drill hole to fire				10.02	7.28	0.91	0.31	81.48	.....	100	.....	G.	17	Very old fire; fumes escaping into general circulation.
1,800 level.				3.20	13.35	0.28	.....	83.13	.....	100	0.04	H.	18	Outside of fire bulkhead.
1,800 raise.	106	106	100	0.71	17.07	0.00	.....	82.22	.....	100	.....	H.	19	Fumes from old fire still burning.
927 crosscut.	94	95	96	2.49	13.38	0.08	.....	84.05	.....	100	.....	B.	20	
949 crosscut.	75	92	44	0.58	19.26	.....	.....	80.16	.....	100	.....	B.	21	
1,432 crosscut.	130+	130+	(?)	1.40	14.70	Tr.	.....	83.90	.....	100	.....	B.	22	

GASES FROM MINE FIRES.

As most of Butte's large mines have connections to other mines for ventilation, fumes from a fire in one mine frequently reach adjoining mines very quickly. If a fire has been burning several years provision is generally made to confine the gases or to conduct them away from other mines; when an old fire breaks out in an unexpected place or a new fire gains much headway before being discovered, the diffusion of gases is often rapid and surrounding mines are endangered.

Table 12 shows analyses of 22 samples of air or fumes from fires in Butte mines. Samples 1 and 2 are typical gases removed from a newly started fire by fairly strong air currents. Sample 3 is the so-called sweet gas, as Butte miners designate it, and the high percentage of CO makes it very dangerous; it generally is found in combatting a mine fire that has had some time to get started in timbered workings. Samples 4, 5, and 6 represent gases from a four-day-old fire in a timbered shaft; though the CO content was not very high, the volume of air passing the point of sampling was over 30,000 cubic feet per minute, hence the CO content near the seat of the fire must have been high and dangerous. Samples 7 to 16 were taken at various stages of the extension of an old fire which raged in old-time back-filled timbered stopes and spread downward with great rapidity. During the early days of the new fire, samples taken in smoky places, Nos. 7, 8, 9, and 10, show dangerous amounts of CO, and appreciable quantities of methane (CH_4), the inflammable gas of coal mines, from which metal mines are supposed to be free; men caught in gases like these could live but a short time.

Sample 11 represents the main return, 125,000 cubic feet per minute, from the fire area; it was taken the same day as samples 7, 8, 9, and 10; this analysis indicates much combustion and great volumes of dangerous CO. Sample 12, taken at the same place four days later, has essentially the same analysis, and sample 13, taken four months later, indicates very little smoke, but possibly some glowing fire. Samples 7 to 14 contain appreciable amounts of SO_2 and those with over 0.1 per cent of it are practically irrespirable. Samples 15 and 16 show remarkably high percentages of methane (CH_4); in fact, small explosions of methane took place in the workings whence they came. These samples also are high in CO_2 , very low oxygen, and high in CO, constituting an atmosphere about as dangerous for respiration as could be found. Sample 18 represents gas from a mine fire still burning after a two months' start in a back-filled timbered stope that had been closed to extinguish the fire; and sample 19 was taken several months later when the fire had apparently been extinguished and the absorption of oxygen was under way.

Samples 20, 21, and 22 were from the region of an old-time fire that was still burning and leaking gas into the mine workings.

Practically every one of the analyses indicates a gas dangerous to breathe. Probably there were still other dangerous gases. One of the main copper ores of Butte carries much arsenic, and arsenical crystals are found deposited near the same opening from old-time Butte fires. hence arsenical fumes or gases would probably be found should chemists look for them.

TABLE 13.—Analyses of samples from fumes of explosives in Butte mines.

Place.	Wet bulb, °F.	Dry bulb, °F.	Relative humidity, per cent.	CO ₂	O ₂	CO	CH ₄	N ₂	H ₂	Mine.	No.	Remarks.
1,466 stope, fifth floor	70½	75	80	0.20	20.62	0.05	.....	79.13	.....	D.	1	One minute after firing two holes with two and four sticks of 40 per cent ammonia explosive. Fair air current, yet men complained of headache from fumes in muck piles.
3,475 crosscut	92	98	79	5.21	18.38	0.94	0.20	74.34	0.43	A.	2	Taken 3 minutes after firing round of 14 holes with 70 pounds of 40 per cent gelatine explosive; used No. 8 electric detonator.
Do.....	92	98	79	6.02	18.23	1.04	0.19	74.04	0.48	A	3	Samples taken same place, but before firing shots.
Do.....	78½	83½	76	0.13	20.84	0.00	0.00	79.03	.....	A.	4	
Do.....	78½	83½	76	0.13	20.85	0.00	0.00	79.02	.....	A.	5	
3,003 drift breast...	85	85½	98	0.05	20.91	0.00	0.00	79.04	0.00	A.	6	Taken 1½ hours after firing round of 13 holes; compressed-air stream was blowing constantly.
3,003 150 feet back from breast.	81	82	91	0.37	20.60	0.07	0.06	78.90	0.00	A.	7	Taken 1½ hours after firing above shots in smoke 150 feet back from breast.
3,475 crosscut	89	97½	71	0.68	20.43	0.05	0.09	78.75	0.00	A.	8	Duplicate of samples taken at breast about 15 minutes after firing round of 13 holes charged with about 68 pounds of 40 per cent gelatine and ammonium explosive; fired electrically.
Do.....	89	97½	71	0.60	20.40	0.07	0.05	78.88	0.00	A.	9	Fumes from muck pile shot with 40 per cent gelatine; headaches.
2,003 drift breast...	74	76	91	0.17	20.73	0.00	0.00	79.10	0.00	A.	10	Supposed to be fumes from 40 per cent gelatine; headaches.
2,254 raise, seventh floor.	83	84	96	0.26	20.56	0.00	0.00	79.18	0.00	A.	11	
2,401 crosscut breast	80	83	88	0.23	20.52	0.00	0.00	79.17	0.00	A.	12	Do.
754 raise, first floor..	76½	76½	100	0.16	20.47	0.00	0.00	79.37	0.00	A.	13	Taken 5 minutes after firing 1 shot with 40 per cent gelatine.
654 drift breast.....	64½	65	98	0.93	19.41	0.00	0.00	79.66	0.00	A.	14	Taken from muck pile blasted 10 hours previously with 40 per cent gelatine; no air circulating and place in old gob.
1,875 drift breast...	75	76	96	0.61	19.49	0.00	0.00	79.93	0.00	A.	15	Fumes from muck pile blasted 2½ hours before by 3 shots of 40 per cent ammonium explosive. Compressed air had been used three-fourths hour after blasting, but no compressed air used for 1½ hours before taking sample. Men complained of headache.

In general, provision is made to exclude these gases from the active workings, but the badly broken ground in certain parts of the Butte district, together with the multiplicity of intermine connections—some accessible, some inaccessible—allow some spreading of gases, to which is chargeable the death of several men and the temporary disability of many more. On one occasion 0.07 per cent CO gas was found on a station, and probably was present in the entire downcast shaft below a certain level, on account of the diversion of gases from their usual course by the temporary closing of a fan. Moreover, some of the long-distance mine fires are confined by concrete structures, and when the ground moves, as it frequently does, fire gases enter the mine workings through cracks in the concrete. With the exception of the leakage of fire gases through broken ground or bulkheads, Butte mines are not troubled by gases issuing from the veins or the country rock, a frequent and serious source of danger in some metal-mining regions.

GASES FROM EXPLOSIVES.

Table 13 contains analyses of 15 air samples taken in Butte mines in order to obtain information relative to gases given off by the 30 to 40 per cent gelatine and ammonia dynamite used almost exclusively in Butte mines.

Sample 1 was taken in a fairly well ventilated stope about one minute after shooting less than 3 pounds of an ammonium explosive, and the headache-producing gas was undoubtedly the 0.05 per cent CO. Samples 2, 3, 4, and 5 show how dangerous gases may foul the air in confined places after a heavy round of shots; samples 4 and 5 were taken at the breast before blasting and represent nearly normal air. Numbers 2 and 3, taken a short time later at the same breast about 3 minutes after firing by electricity a round of 14 holes in hard granite loaded with about 70 pounds of 40 per cent gelatine explosive, show a large percentage of CO₂, much oxygen depletion, and a dangerous amount of CO. Samples 8 and 9, taken in the same place as samples 2 and 3, but on a different day and about 15 minutes after a round of about 68 pounds of explosives, three-fourths gelatine and one-fourth ammonia dynamite, also show considerable quantities of CO.

Samples 6 and 7 indicate the inefficiency of compressed air for ventilation: sample 6 was taken at the breast of a drift about one and one-half hours after firing a round of 13 holes, during which period a compressed-air hose had been blowing a full stream, sample 6 being taken about 5 feet from the end of blowing hose, but not in the moving air stream, hence in practically normal air. Sample 7 was taken at a point in the drift about 150 feet from the breast in a

smoky zone at least 200 feet long, the smoke being slowly moved from the breast by the compressed air. This sample showed 0.07 per cent CO and 0.06 per cent CH_4 , an atmosphere readily producing headache. Samples 10 to 15 were taken at places where shovellers complained of having headache from explosive fumes from the piles of "muck" shot down by gelatine or ammonia explosives. These analyses fail to show CO and only two show excessive oxygen depletion or the formation of CO_2 . The headache may have been caused by the cumulative effect of breathing minute quantities of oxides of nitrogen or of CO probably present but not given in the analyses.

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TABLE 14.—Record of air movement at working places in mine A, a Butte mine with better ventilation than the average.

	Stopes.		Raises.		Drifts.		Crosscuts.		Totals.		Per cent.	
	Com- fort- able.	Uncomfortable.	Com- fort- able.	Uncomfortable.	Com- fort- able.	Uncomfortable.	Com- fort- able.	Uncomfortable.	Com- fort- able.	Un- com- fort- able.	Totals.	Per cent.
Good.....	a 5	3	8		b 18	0	c 14	0	39	42	100	26.6
Slight.....	6	7	13		0	3	11	2	17	29	100	18.3
None.....	9	39	48		8	11	1	3	22	87	100	55.1
Total.....	20	49	69		26	14	26	5	78	158	.....	100

^a One place had air movement due to small fan and canvas pipe.^b Two places had air movement due to small fan and canvas pipe.^c Seven places had air movement due to small fan and canvas pipe.

In Table 13 the analyses show the dangerous gases found in confined places in Butte mines after blasting, and indicate the necessity for active circulation of air at working faces. During the investigation it was not uncommon to encounter workers at the face, especially shovelers, suffering from headache or nausea due to explosive fumes, though blasting might have been done several hours before. The suspicion existed that much of this illness was imaginary, or that it was a pretense to influence the investigators adversely to existing conditions, yet an inspection of Table 13 and of Table 14, "Record of Air Movement" in one of the typical large mines, reveals that in 55 per cent of all the underground places in which men were working there was absolutely no movement of air, and in an additional 18.3 per cent the movement was slight. It can readily be seen therefore that fumes from explosives may be considered dangerous to both health and life when ventilation is defective.

Complete detonation of a pound of 40 per cent gelatine explosive generates approximately one-third of a cubic foot of CO gas, hence a round of approximately 70 pounds of such explosive generates about 23 cubic feet. In a drift or crosscut measuring 5 by 7 feet, and hence having a volume of 35 cubic feet per linear foot, 23 cubic feet of CO gas would completely fill 100 linear feet with a gaseous mixture containing 0.66 per cent CO, a very dangerous atmosphere. The danger is accentuated by the fact that the mixture probably would not be uniform and in places the CO content would much exceed 0.66 per cent.

Investigation showed that the ordinary compressed-air blower in Butte mines delivered only 125 cubic feet of air per minute even under a pressure of 80 pounds per square inch. Such a volume of air liberated at a drift of 35 feet cross section would remove the fumes at a rate less than 4 linear feet per minute if it acted simultaneously at all points in the cross section; if it acted as it probably would only through certain parts of the cross section, the air would move more swiftly through these points, but pockets of the concentrated gases would be left along the drift for considerable periods of time. The introduction of 10,000 cubic feet of air per minute by bratticing, or by canvas or galvanized tubing, would effect prompt removal or dilution of the gases.

GASES FROM COMPRESSED AIR.

In the best ventilated mines of Butte only 10 to 20 per cent of the total air supply comes from the compressed-air lines; and in some of the poorly ventilated properties compressed air forms 50 to 80 per cent of the supply, and the entire supply for parts of some mines is

compressed air. Moreover, in one of the large mines in which detailed investigation of all working places was made 75 out of the 158 places visited were using compressed air for ventilation. In another mine over 50 per cent of all places were using compressed air for ventilation. Generally, though not invariably, compressed air was used because no other adequate air supply was available. The quality of the compressed air, therefore, as may be seen readily, is of much importance.

At various times the investigators were informed that compressed air, especially the exhaust from pumps or even from drills, made the miners ill. Several samples of compressed air were taken and analyzed. The two given below are typical.

Analyses of compressed air from Butte mines.

Place.	CO ₂ .	O ₂ .	CO.	CH ₄ .	N ₂ .	Total.	Remarks.
1,500	0.09	20.80	0.00	0.00	79.11	100	Exhaust from pumps.
2206 stope, 24th floor....	0.06	20.82	0.00	0.00	79.12	100	Taken at end of air hose.

Compressed air exhaust from pumps or drills might contain finely divided oil that would nauseate those who breathed it; moreover, compressed air might contain dangerous gases owing to faulty conditions in the compressor or receivers, but the samples of compressed air taken in Butte mines revealed no such gases.

DETAILS OF BUTTE MINE EXAMINATIONS.

In the foregoing discussion of the abstract principles of metal-mine ventilation as applied to conditions in the Butte district, reference was occasionally made to data obtained by the investigators in the mines. In the following pages some of the data is discussed. As previously stated, all working places in four mines were examined carefully, and less detailed examinations were made in about 20 additional mines, approximately 2½ years being spent on the work. The data obtained in one of the deepest, most extensive, and most productive mines, here designated as mine A, were tabulated and are given herewith. In a subsequent summation, comparative data are given on this mine and two others, B and D. In one of these other mines a fire has been burning many years, and in the second is a partly extinguished fire; both have fan ventilation and may be considered two of the progressive mines of the district, the ventilation and working conditions of which are much above the average. Both B and D mines have workings at practically all horizons from the surface to below the 1,500-foot level and one has workings to the 2,500-foot.

VENTILATION IN MINE A.

Table 5 (pp. 18 and 19) gives detailed data on temperatures and humidities at the surface and at various points in the main downcast shaft of one of the best ventilated mines in Butte—mine A. Figures 36 and 37 give data as to temperature and the volume of air delivered

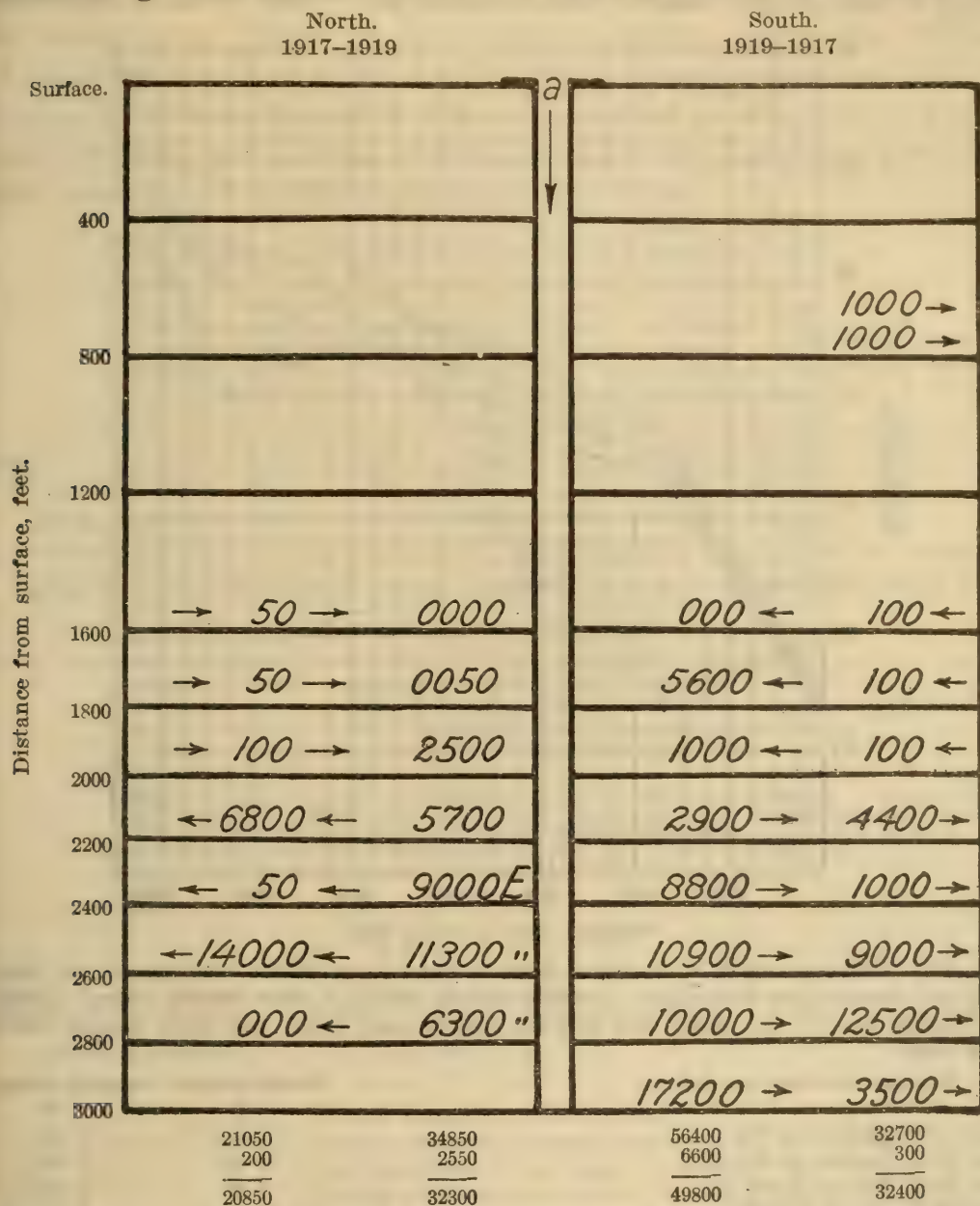


FIG. 36.—Volume of air distributed from a downcast shaft of mine A, 1917 with rough, timber lining; 1919 with smooth lining: Total for 1917, 20,850 + 32,400=53,250; for 1919, 32,300 + 49,800=82,100; a, shaft collar, arrows indicate direction of air flow.

before and after the shaft was smooth lined. Figures 4, 5, 7, 8, 11, and 28 also give data obtained in this shaft before it was smooth lined. The data in Table 5 were obtained before the smooth lining was done.

On the 1,800 and 2,000 foot levels 9,150 cubic feet of return mine air goes into the downcast shaft at 77° F., mixing with 82,100 cubic

feet of fresh air at 41° F., the combination being 91,250 cubic feet at 45° F. Hence, the return air takes about 9 per cent of the air capacity of the shaft and increases the temperature of the downcasting air 4 per cent. Figure 36 shows the flow of air from downcasting shaft in 1917 when the shaft had ordinary timber lining and in 1919 after it was smooth lined. The increase in volume from 53,250 cubic

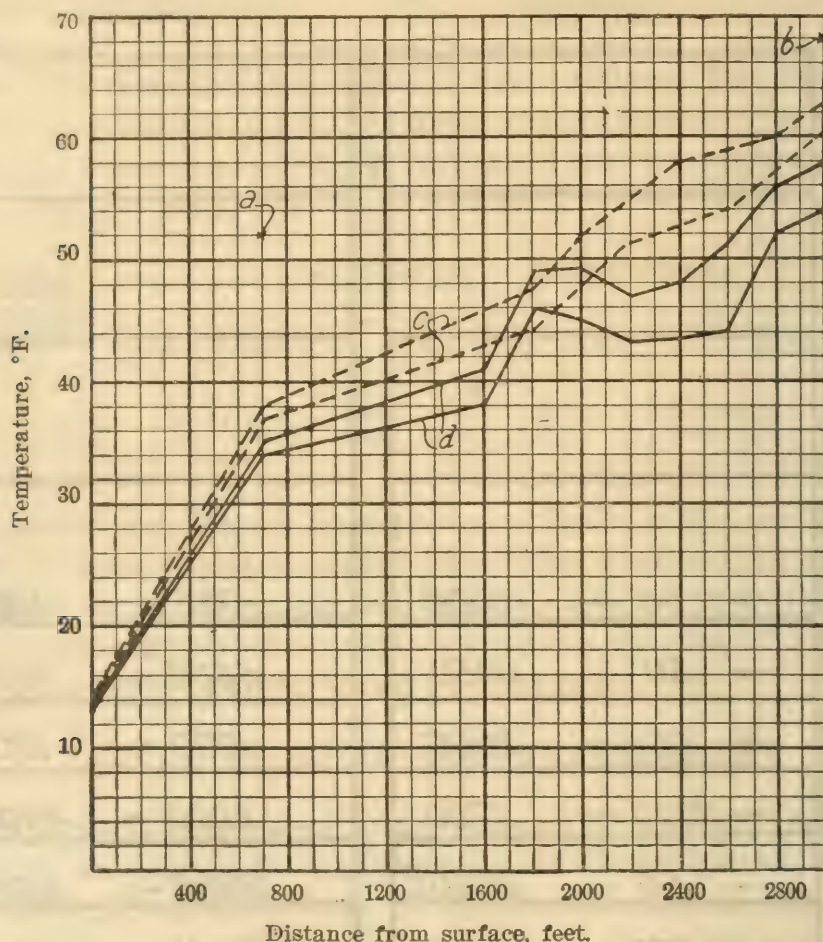


FIG. 37.—Temperatures in a downcast shaft of mine A: *a*, Water temperature on level; *b*, rock temperature on station; *c*, before smooth lining; *d*, after smooth lining; surface temperature, 14° F. Same fans and fan motors used before and after smooth lining of shaft.

Average increase per 100 ft.	Rough lining.	Smooth lining.
	° F.	° F.
Wet bulb, surface to 700 ft.-----	3.43	3.00
Dry bulb, surface to 700 ft.-----	3.43	3.00
Wet bulb, 700 to 2,600 ft.-----	0.90	0.46
Dry bulb, 700 to 2,600 ft.-----	1.10	0.53

Average velocity, surface to 700 ft., 700 ft. a min. rough lining, 1,050 ft. smooth lining; at 2,600 ft., 500 ft. a min. rough lining, 700 ft. smooth lining.

feet a minute in 1917 to 82,100 cubic feet in 1919, or 54 per cent increase using the same fans and motors, is due to the smooth lining.

Tables 17, 18, 19, and 20 give detailed data obtained in 158 working places visited in this mine during several months. These tables subdivide the various kinds of working places—stopes, raises, drifts, and crosscuts—into those rated “comfortable” or “uncomfortable,”

the temperature, humidity, dampness, and air movements being given for each place; and for most places the occupation of the worker and whether compressed air was being used. Tables 15 and 16 summarize Tables 17, 18, 19, and 20. Seventy-eight places were rated comfortable and 80 uncomfortable. Table 14 classifies the working places as comfortable and uncomfortable and records the air movements. Table 15 gives data regarding dampness. Table 21 classifies the various kinds of working places, elsewhere classed as comfortable or uncomfortable, with respect to wet bulb and dry bulb temperatures, and the percentage of relative humidity, and also with respect to the various depths underground.

TABLE 15.—*Conditions as to dampness in mine A.*

	Stopes, number of places.	Raises, number of places.	Drifts, number of places.	Cross- cuts, number of places.	Total.		Comfort- able places.	Uncom- fortable places.
					Number.	Per cent.		
Damp.....	18	2	16	9	45	28.5	28	17
Dry.....	51	16	24	22	113	71.5	50	63
Total.....	69	18	40	31	158	100	78	80

TABLE 16.—*Classification of places, comfortable and uncomfortable, mine A.*

Places classed as uncomfortable.

Places.	Temperature and humidity.			Air movement.		Dampness.		Num- ber places.	Percent- ages.		To- tal.
	Wet bulb, °F.	Dry bulb, °F.	Rela- tive hu- mid- ity, per cent.	Fair.	None.	Damp.	Dry.		Com- fort- able.	Un- com- fort- able.	
Stopes.....	73.6	75.3	92.2	11	9	7	13	20	.....	.....	.....
Raises.....	74.2	76.3	91.2	2	4	1	5	6	.....	.....	.....
Drifts.....	71.5	74.1	88.9	18	8	12	14	26	.....	.....	.....
Crosscuts.....	71.0	74.2	83.9	25	1	8	18	26	.....	.....	.....
Totals and averages.....	72.1	74.6	88.2	56	22	28	50	78	.....	.....	.....

Places classed as comfortable.

Stopes.....	81.5	82.8	94.6	10	39	11	38	49	.....	.....	.....
Raises.....	83.2	84.4	95.0	0	12	1	11	12	.....	.....	.....
Drifts.....	79.7	81.7	92.1	3	11	4	10	14	.....	.....	.....
Crosscuts.....	81.2	82.6	94.2	2	3	1	4	5	.....	.....	.....
Totals and averages.....	81.4	82.8	94.2	15	65	17	63	80	.....	.....	.....

Classification of all places.

Stopes.....	79.2	80.6	93.9	21	48	18	51	69	29	71	100
Raises.....	80.2	81.7	93.7	2	16	2	16	18	33½	66½	100
Drifts.....	74.3	76.7	90.0	21	19	16	24	40	65	35	100
Crosscuts.....	72.7	75.5	85.5	27	4	9	22	31	84	16	100
Totals and averages.....	76.8	78.8	91.3	71	87	45	113	158	.....	.....	.....

TABLE 17.—*Stopes in mine A.*Places classed as comfortable.^a

Description.	Temperature and humidity.			Air movement.			Wetness.	
	Wet bulb, ° F.	Dry bulb, ° F.	Humidity, per cent.	None.	Fair.	No record.	Damp.	Dry.
Driller using air, 6th floor, 734 stope.....	61	62	94	1	.....	.....	1	.....
Running waste car in stope; no compressed air....	61	62	94	1	.....	.....	1	.....
Shoveling, no compressed air.....	61	63	89	1	.....	.....	1	.....
Mucking and timbering.....	61½	63	92	1	.....	.....	1	.....
Drilling, rill stope; using compressed air.....	79	80	96	.....	1	.....	.....	1
Do.....	79	81	91	.....	1	.....	.....	1
Timbering; no compressed air ^b	81	81½	98	.....	1	(c)	.....	1
Mucking; no compressed air ^b	76	78	91	.....	1	.....	.....	1
Drilling; using compressed air ^b	78	79	96	.....	1	.....	.....	1
Do.....	66	71½	74	1	.....	.....	.....	1
Drilling, rill; using compressed air ^b	81	83	92	Slight.	1	.....	.....	1
Timbering; no compressed air.....	78	81	87	Fair.	1	.....	.....	1
Drilling, rill; using compressed air.....	84	86	92	Fair.	1	.....	.....	1
Do.....	81	83	92	Fair.	1	.....	.....	1
Mucking, rill; no compressed air.....	82	84	92	Fair.	1	.....	.....	1
Do.....	82	84	92	Good.	1	.....	.....	1
Mucking 623 stope; no compressed air.....	62½	63½	94	1	.....	.....	1	.....
Drilling 455 stope; using compressed air.....	71	71½	97	1	.....	.....	.....	1
Barring 453 stope; no compressed air.....	73	74	95	1	.....	.....	1	.....
Mucking 456 stope; no compressed air ^b	74	75	95	1	.....	.....	1	.....
	73.6	75.3	92.2	9	11	.....	7	13

Places classed as uncomfortable.^d

Hand-auger drilling; no compressed air.....	76	78	91	1	.....	.....	1	.....
Mucking; no compressed air.....	84	85	96	1	.....	.....	1	.....
Drilling; using compressed air.....	84½	85½	96	1	.....	.....	.....	1
Just finished drilling; using compressed air.....	83	84	96	1	.....	.....	.....	1
Drilling; using compressed air.....	75	76	95	1	.....	.....	.....	1
Do.....	80	81	96	1	.....	.....	1	.....
Do.....	82	83½	93	1	.....	.....	1	.....
Just finished drilling; using compressed air.....	81	82	96	1	.....	.....	1	.....
Timbering; no compressed air.....	80½	82	93	1	.....	.....	.....	1
Mucking; using compressed air.....	80	81½	93	1	.....	.....	.....	1
Drilling; using compressed air.....	82½	83	98	1	.....	.....	.....	1
Barring down; using compressed air.....	80½	82	93	1	.....	.....	.....	1
Drilling; using compressed air.....	82½	83	98	1	.....	.....	.....	1
Do.....	73	76	87	1	.....	.....	.....	1
Timbering; no compressed air.....	75	77½	89	1	.....	.....	.....	1
Mucking, rill; no compressed air.....	79	80	96	Slight.	1	.....	1	.....
Do.....	80	81	96	1	.....	.....	1	.....
Drilling; using compressed air.....	81	82	96	1	.....	.....	.....	1
Mucking; no compressed air.....	81	81½	98	1	.....	.....	.....	1
Timbering; no compressed air.....	82½	83	98	Slight.	1	.....	.....	1
Drilling; using compressed air.....	82	82½	98	1	.....	.....	.....	1
Mucking; no compressed air.....	81	83	92	1	.....	.....	.....	1
Dumping waste, rill; no compressed air.....	84	85	96	1	.....	.....	.....	1
Mucking; using compressed air.....	84½	86½	92	1	.....	.....	.....	1
Drilling; using compressed air.....	83	84	96	Slight.	1	.....	.....	1
Mucking; using compressed air.....	83	83½	98	1	.....	.....	.....	1
Drilling, rill; using compressed air.....	83	83½	98	Slight.	1	.....	.....	1
Do.....	85	86	96	1	.....	.....	1	.....
Mucking; using compressed air.....	83½	85	94	1	.....	.....	1	.....
Drilling; using compressed air.....	81	82	96	Fair.	1	.....	.....	1
Timbering; no compressed air.....	81	82½	94	Slight.	1	.....	.....	1
Drilling; using compressed air.....	84	85	96	1	.....	.....	.....	1
Mucking; using compressed air.....	84	84½	98	1	.....	.....	.....	1
Drilling; using compressed air.....	76	79	87	Slight.	1	.....	.....	1
Do.....	79	81	92	1	.....	.....	.....	1

^a Twenty places comfortable of which 7 were only "fair," 9 were using compressed air, 11 were not using compressed air; 7 were rill stopes, 13 were square-set stopes.^b Indicates place only fairly comfortable.^c Velocity 80 feet per minute.^d 49 places rated uncomfortable: 36 were using compressed air, 13 were not using compressed air; 7 were rill stopes, 42 were square-set stopes.

TABLE 17.—*Stopes in mine A—Continued.*

Places classed as comfortable—Continued.

Description.	Temperature and humidity.			Air movement.			Wetness.	
	Wet bulb, °F.	Dry bulb, °F.	Humidity, per cent.	None.	Fair.	No record.	Damp.	Dry.
Drilling, rill; using compressed air.....	78	79½	93	Fair.	1	.....	1	.....
Do.....	76	79	87	1	.....	.....	.....	1
Do.....	78½	80	93	1	.....	.....	.....	1
Do.....	86	86½	98	1	.....	.....	.....	1
Timbering; using compressed air.....	87½	88	98	1	.....	.....	.....	1
Drilling; using compressed air.....	82½	84	94	1	.....	.....	1	.....
Mucking, rill; using compressed air.....	86	87	96	Slight.	1	.....	.....	1
Drilling; using compressed air.....	82½	85	90	1	.....	.....	.....	1
Do.....	82	83½	94	1	.....	.....	.....	1
Timbering; no compressed air.....	77½	79	93	1	.....	.....	.....	1
Do.....	79½	81	93	Fair.	1	.....	.....	1
Drilling, rill; using compressed air.....	87	88	96	1	.....	.....	.....	1
Mucking; using compressed air.....	87	87½	98	1	.....	.....	.....	1
Do.....	87	88	96	1	.....	.....	.....	1
	81.5	82.8	94.6	39	10	.....	11	38

TABLE 18.—*Raises in mine A.*

Places classed as comfortable.^a

	Temperature and humidity.			Air movement.			Dampness.	
	Wet bulb.	Dry bulb.	Humidity.	None.	Fair.	No record.	Damp.	Dry.
Timbering; no compressed air ^b	76½	77½	96	1	.....	.....	.....	1
Drilling; using compressed air ^{b c}	75	77	91	1	.....	.....	.....	1
Mucking; no compressed air ^b	78	79	96	Fair.	1	.....	.....	1
Timbering; using compressed air, 2 jets ^b	77	79	91	1	.....	.....	.....	1
Drilling; fan ^d using compressed air.....	77	83	76	Fair.	1	.....	.....	1
Timbering; no compressed air.....	62	62½	97	1	.....	.....	1	.....
	74.2	76.3	91.2	4	2	.....	1	5

Places classed as uncomfortable.^e

Drilling; using compressed air.....	78	79	96	1	.....	.....	.....	1
Do.....	81	82½	94	1	.....	.....	.....	1
Mucking; using compressed air.....	83	84	96	1	.....	.....	.....	1
Timbering; no compressed air.....	80½	81	98	1	.....	.....	1	.....
Timbering; using compressed air.....	82	83	96	1	.....	.....	.....	1
Drilling; using compressed air.....	83	84	96	1	.....	.....	.....	1
Do.....	90	90½	98	1	.....	.....	.....	1
Hoisting timber; using compressed air.....	87	88	96	1	.....	.....	.....	1
Mucking; no compressed air.....	83½	87	86	1	.....	.....	.....	1
Timbering; no compressed air.....	82	84	92	1	.....	.....	.....	1
After shooting; using compressed air.....	85	86	96	1	.....	.....	.....	1
	83.2	84.4	95	12	.....	.....	1	11

^a Six places rated as comfortable, 13 were using compressed air; 3 were not using compressed air.
^b Indicates places only fairly comfortable.
^c Raise had just broken through to upper level, hence the air circulation.
^d Canvas pipe from fan goes to eleventh floor and readings on twelfth floor.
^e Twelve places rated as uncomfortable; 9 using compressed air; 3 not using compressed air.

TABLE 19.—*Drifts in mine A.*Places classed as comfortable.^a

Description.	Temperature and humidity.			Air movement.			Wetness.	
	Wet bulb, °F.	Dry bulb, °F.	Humidity, per cent.	None.	Fair.	No record.	Damp.	Dry.
Mucking; no compressed air ^b	62½	64	92	1	.....	.....	1	.....
Timbering; no compressed air ^b	60½	61½	94	1	.....	.....	1	.....
Mucking; no compressed air ^b	61	62½	92	1	.....	.....	1	.....
Timbering; no compressed air.....	71½	76	80	.....	Good..	.....	1	.....
Loading from chute; no compressed air ^c	77	78	96	.....	do.....	.....	.....	1
Drilling; using compressed air ^{b c}	74	76	91	1	.....	.....	.....	1
Clean track; no compressed air.....	69½	74	80	.....	Good..	.....	.....	1
Do.. no compressed air.....	77	78	96	.....	do.....	.....	1	.....
Mucking; no compressed air ^b	^d 58	68	54	.....	do.....	.....	.....	1
Mucking; fan; no compressed air.....	76½	77½	96	.....	do.....	.....	1	.....
Do.. no compressed air.....	70	71	95	.....	do.....	.....	1	.....
Do.. no compressed air ^c	84	85	96	.....	do.....	.....	.....	1
Do.. no compressed air.....	77½	82	81	.....	do.....	.....	.....	1
Drilling; using compressed air.....	80	81	96	.....	do.....	.....	.....	1
Mucking; using compressed air ^{b c}	76½	80	83	1	.....	.....	.....	1
Loading from chute; no compressed air ^c	81½	84	90	.....	Good..	.....	.....	1
Do.. no compressed air.....	77	82	80	.....	do.....	.....	.....	1
Drilling; using compressed air.....	79½	83	86	.....	do.....	.....	.....	1
Dump waste; no compressed air.....	75	77½	89	.....	do.....	.....	.....	1
Repair track; no compressed air.....	67	70	86	.....	do.....	.....	.....	1
Mucking; fan; no compressed air ^b	76	78	91	.....	do.....	.....	1	.....
Do.. no compressed air.....	82½	83	98	.....	do.....	.....	1	.....
Do.. no compressed air.....	64½	70	74	.....	do.....	.....	.....	1
Mucking; no compressed air ^b	64½	65	97	1	.....	.....	1	.....
Barring down; no compressed air ^b	62½	63	97	1	.....	.....	1	.....
Timbering; no compressed air ^b	56	56	100	1	.....	.....	1	.....
	71.5	74.1	88.9	8	18	.....	12	14

Places classed as uncomfortable.^e

Mucking; no compressed air ^b	74	76	91	1	.....	.....	1	.....
Do. ^b	79	80	96	1	.....	.....	.....	1
Do. ^b	75	76	95	1	.....	.....	1	.....
Drilling; using compressed air ^b	79	80	96	1	.....	.....	.....	1
Do.. no compressed air.....	78½	79	98	1	.....	.....	1	.....
Drilling; using compressed air ^b	79	79½	98	1	.....	.....	.....	1
Loading from chute; no compressed air.....	81½	84	90	.....	1	.....	.....	1
Mucking; using compressed air ^b	79	81½	90	1	.....	.....	.....	1
Do. ^b	81	83	92	1	.....	.....	.....	1
Mucking; no compressed air ^b	79	80½	94	1	.....	.....	1	.....
Drilling; using compressed air.....	79½	80½	96	Slight.	1	.....	.....	.....
Do. ^b	83	84½	94	1	.....	.....	.....	1
Timbering; no compressed air.....	81½	84	90	Slight.	1	.....	.....	1
Do.. no compressed air.....	86	95	69	1	.....	.....	.....	1
	79.7	81.7	92.1	11	1	.....	4	10

^a 26 places rated as comfortable; 10 at breast, 16 not at breast; 4 using compressed air, 22 not using compressed air.^b Readings taken at breast.^c Place only fairly comfortable.^d Place just starting off main air course.^e 14 places rated as uncomfortable: 10 were at breast, 4 not at breast; 6 using compressed air, 8 not using compressed air.

TABLE 20.—*Crosscuts in mine A.*Places classed as comfortable.^a

Description.	Temperature and humidity.			Air movement.			Wetness.	
	Wet bulb, °F.	Dry bulb, °F.	Humidity.	None.	Fair.	No record.	Damp.	Dry.
Dumping; no compressed air	75½	76	95		e 1		1	
Do.	80	80½	98		e 1		1	
Mucking; no compressed air ^{b c}	73½	75½	91	1				1
Do.	64	71	68		e 1			1
Do.	61½	68½	67		e 1			1
Do.	58½	66½	61		e 1			1
Do.	51½	58	63		1			1
Do.	52	58	66		1			1
Drilling; using compressed air	73	74½	93		1			1
Do.	73	74½	93		1			1
Mucking; fan; no compressed air	76½	78½	91		1			1
Do. using compressed air	77	79	91		1			1
Do. no compressed air	77	79½	90		1			1
Do. c. do.	71½	76½	78		1		1	
Do. do.	51	55	76		e 1			1
Drilling; fan; using compressed air ^{b c}	89	97½	71		e 1			1
Do. b c.	77½	83½	76		1			1
Do. b c.	70½	78	69		1			1
Dumping; no compressed air	53	57	77		e 1			1
Do.	72½	73½	95		1			1
Do. do.	81½	82	98		e 1		1	
Do. do.	81	81½	98		e 1		1	
Do. do.	80½	81	97		e 1		1	
Clean track; no compressed air	79½	79½	100		e 1		1	
Do. do.	78	78½	98		e 1		1	
Do. do.	63½	67½	81		e 1			1
	71.0	74.2	83.9	1	25		8	18

Places classed as uncomfortable.^d

Drilling; using compressed air	82	82½	98	1				1
Working on chute; no compressed air	83	83	100	(f)	1		1	
Mucking; using compressed air ^c	84½	85½	96	(f)	1			1
Do. c.	80	83	88	1				1
Do. c.	76½	79	89	1				1
	81.2	82.6	94.2	3	2		1	4

^a 26 places classed as comfortable: 5 taken at breast, 21 not taken at breast; 6 using compressed air, 20 not using compressed air.^b Place only fairly comfortable.^c Readings taken at breast.^d 5 places classed as uncomfortable: 3 taken at breast, 2 not taken at breast; 2 using compressed air, 3 not using compressed air.^e Good air current.^f Slight air movement.

DISCUSSION OF DATA OBTAINED IN MINE A.

Mine A, though connected to other mines and at times exchanging air with them, has its own downcast shaft together with three upcast shafts, all of which have modern fans at the surface well housed and capable of being reversed with a minimum expenditure of time or effort. Though mine A interchanges air with its neighbors, it is entirely independent of them in air supply or circulation; in general, the connections to other mines are an actual disadvantage as far as ventilation is concerned, for they serve mainly to transmit poisonous fumes to or from the mine during fires. This mine is extensive; it has over 30 miles of sill workings with probably sev-

eral times that amount of raises and stopes, it employs more than 400 men underground per shift, and stopes in about a dozen different veins at nearly all horizons from the surface to below the 3,000-foot level. The mine has no mine fires, but temperatures are somewhat high because of the rock temperatures at depth. (See Fig. 6 and Table 6, p. 21.)

In addition to having over 50,000 cubic feet of fresh surface air from the downcast shaft and over 10,000 cubic feet of compressed air per minute, this mine has been experimenting with the use of small electrically driven fans to force air through canvas tubing in order to relieve the unhealthful conditions at blind-end faces of crosscuts and drifts. As it proved eminently successful, the method was tried also in a few raises and in stopes.

TABLE 21.—*Classification of places in mine A, by wet and dry bulb temperatures, and by depths below surface.*

	Stopes.						Raises.						Drifts.						Crosscuts.						Totals.	Per cent
	Under 70.	70 to 75.	75 to 80.	80 to 85.	85 to 90.	90 and over.	Total.	Under 70.	70 to 75.	75 to 80.	80 to 85.	85 to 90.	90 and over.	Total.	Under 70.	70 to 75.	75 to 80.	80 to 85.	85 to 90.	90 and over.	Total.					
Surface to 1,000.....	5	3	1	0	0	0	9	1	0	1	0	0	0	2	6	1	0	0	0	0	0	7				
1,000 to 2,000.....	0	0	1	2	0	0	3	0	0	0	0	0	0	0	0	0	1	1	0	0	0	4				
2,000 to 2,500.....	1	1	6	24	1	0	33	0	0	4	5	0	1	10	3	3	10	4	0	0	0	20				
2,500 to 3,000.....	0	0	8	10	6	0	24	0	0	1	3	2	0	6	0	0	5	3	0	0	0	9				
3,000 to 3,500.....	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0				
Totals.....	6	4	16	36	7	0	69	1	0	6	8	2	1	18	10	4	17	8	1	0	0	40				

DRY BULB, °F.

	5	2	2	0	0	0	9	1	0	0	0	0	0	6	0	1	0	0	7	0	0	1	0	0	0	0	1	19	12½
Surface to 1,000.....	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	0	0	1	8	5
1,000 to 2,000.....	0	0	1	20	7	0	33	0	0	4	5	0	1	10	0	0	2	8	20	1	1	0	0	0	0	0	12	75	47½
2,000 to 2,500.....	0	0	5	9	11	0	24	0	0	0	3	3	0	6	0	0	6	0	9	1	0	2	0	0	0	0	9	48	30
2,500 to 3,000.....	0	0	4	9	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	6	0	4	1	0	0	0	8	50	5
3,000 to 3,500.....	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	1	0	0	1	8	48	3
Totals.....	5	3	12	31	18	0	69	1	0	5	8	3	1	18	7	4	12	15	1	40	7	4	9	9	1	1	31	158	100

RELATIVE HUMIDITY, PER CENT.

	Under 75.	75 to 80.	80 to 85.	85 to 90.	90 to 95.	95 and over.	Total.	Under 75.	75 to 80.	80 to 85.	85 to 90.	90 to 95.	95 and over.	Total.	Per cent.
Surface to 1,000.....	0	0	0	1	5	3	9	0	0	0	0	0	2	7	12½
1,000 to 2,000.....	0	0	0	1	1	2	3	0	0	0	0	0	0	4	5
2,000 to 2,500.....	1	0	0	2	8	22	33	0	0	0	0	3	7	20	47½
2,500 to 3,000.....	0	0	0	3	14	7	24	0	1	0	0	1	0	9	30
3,000 to 3,500.....	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Totals.....	1	0	0	6	28	34	69	0	1	0	3	4	12	40	100

TEMPERATURE AND HUMIDITY.

WET-BULB READINGS.

Table 16 shows that the average wet-bulb temperature of the 158 places visited was 76.8°, the average dry-bulb temperature 78.8° F., and the average relative humidity 91.3 per cent; these figures are remarkably low, as 131 out of the 158 places were below the 2,000-foot level, as shown in Table 21, hence had original rock temperatures above 85°, and 56 places were below the 2,500 with original rock temperatures over 90° F. Only 29 per cent of the 69 stopes were rated comfortable, and of the 20 comfortable stopes 7 were only "fair." Of the 18 raises 33 $\frac{1}{3}$ per cent were rated comfortable, 4 of the 6 comfortable raises being fair, and the only really comfortable raises were one with a temperature of only 62 $\frac{1}{2}$ ° F. and another with low humidity, 76 per cent, and considerable air movement, due to a canvas pipe and a fan. Of the 40 drifts 65 per cent were comfortable, 5 of the 26 comfortable drifts being fair, and but 10 of the 26 readings being at drift faces, the other drift readings being in main air courses. Of the 31 crosscuts 84 per cent were rated comfortable, 5 of the 26 comfortable crosscuts being only fair, and only five readings being at crosscut faces or blind ends.

TABLE 22.—Classification of places in mine A, according to wet and dry bulb temperatures, and relative humidity.

Wet-bulb readings.

Degrees Fahrenheit.	Stopes.			Raises.			Drifts.			Crosscuts.			Totals.	
	Comfortable.	Uncomfortable.	Total.	Comfortable.	Uncomfortable.	Total.	Comfortable.	Uncomfortable.	Total.	Comfortable.	Uncomfortable.	Total.	Comfortable.	Uncomfortable.
Under 70.....	6	0	6	1	0	1	10	0	10	8	0	8	25	0
70 to 75.....	3	1	4	0	0	0	3	1	4	7	0	7	13	2
75 to 80.....	5	11	16	5	1	6	10	7	17	5	1	6	25	20
80 to 85.....	6	30	36	0	8	8	3	5	8	5	4	9	14	47
85 to 90.....	0	7	7	0	2	2	0	1	1	1	0	1	1	10
90 and over.....	0	0	0	0	1	1	0	0	0	0	0	0	0	1
Total.....	20	49	69	6	12	18	26	14	40	26	5	31	78	80

Dry-bulb readings.

Under 70.....	5	0	5	1	0	1	7	0	7	7	0	7	20	0
70 to 75.....	3	0	3	0	0	0	4	0	4	4	0	4	11	0
75 to 80.....	3	9	12	4	1	5	7	5	12	9	0	9	23	15
80 to 85.....	8	23	31	1	7	8	7	8	15	5	4	9	21	42
85 to 90.....	1	17	18	0	3	3	1	0	1	0	1	1	2	21
90 and over.....	0	0	0	0	1	1	0	1	1	1	0	1	1	2
Total.....	20	49	69	6	12	18	26	14	40	26	5	31	78	80

TABLE 22.—*Classification of places in mine A, etc.*—Continued.

Relative humidity.

Degrees Fahrenheit.	Stopes.			Raises.			Drifts.			Crosscuts.			Totals.	
	Comfortable.	Uncomfortable.	Total.	Comfortable.	Uncomfortable.	Total.	Comfortable.	Uncomfortable.	Total.	Comfortable.	Uncomfortable.	Total.	Comfortable.	Uncomfortable.
Under 75.....	1	0	1	0	0	0	2	1	3	7	0	7	10	1
75 to 80.....	0	0	0	1	0	1	0	0	0	4	0	4	5	0
80 to 85.....	0	0	0	0	0	0	5	0	5	1	0	1	6	0
85 to 90.....	2	4	6	0	1	1	3	0	3	0	2	2	5	7
90 to 95.....	11	17	28	2	2	4	6	7	13	6	0	6	25	26
95 and over.....	6	28	34	3	9	12	10	6	16	8	3	11	27	46
Total.....	20	49	69	6	12	18	26	14	40	26	5	31	78	80

An inspection of Table 22 shows that the only stopes uniformly rated comfortable were those with a wet-bulb temperature less than 75° F.; stopes with wet-bulb temperatures between 75° and 80° were about one-third comfortable and two-thirds uncomfortable, all the five stopes constituting this one-third having fair air movement. (See Table 17, p. 80.) Similarly, of the 36 stopes with wet-bulb readings between 80° and 85°, six were rated comfortable and the entire six had fair or good air movement. Thus it seems that in still or stagnant air the maximum wet-bulb reading for a comfortable place was below 75° F.; stopes with wet-bulb temperature between 75° and 85° F., but with accompanying fair or good air movement were rated comfortable, but no stopes with wet bulb above 85°, either with or without air movement, were called comfortable.

Of the six raises given a rating as comfortable one had a wet-bulb temperature of only 62° F.; one with a wet-bulb temperature of 77° had a strong current of air of low humidity from a canvas ventilating pipe, and the other four, one of which had recently broken through to the level above and had some air movement, were rated as only fairly comfortable. The only raises rated comfortable without qualification had less than 75° temperature or had good or fair air movement. Of the 12 raises rated uncomfortable none had discernible air movement and all had temperatures above 80°; the 12 raises were rated uncomfortable notwithstanding that nine of the 12 were using compressed air for ventilation.

Of 26 drifts rated comfortable 18 had fair or good air movement and in the other 8 the wet-bulb temperature was less than 75°; in 17 of these drifts readings were taken at the breast. Of 14 uncomfortable drifts, reading in 10 being at the breast, there was no air movement in 11.

Of 26 comfortable crosscuts, readings in 5 being at breasts, there was fair or good air movement in 25, the one comfortable crosscut without visible air movement having a temperature less than 75° F. It is noticeable that the face of a crosscut with a wet-bulb temperature of 89° F. was rated fairly comfortable; it was supplied with about 2,500 cubic feet of air per minute (velocity nearly 4,000 feet per minute) from the end of the canvas pipe, relative humidity being but 71 per cent.

In stagnant air the maximum wet-bulb reading that may be expected to give a rating of comfortable is 75° F.; with a fair air velocity, 100 or more linear feet per minute, wet-bulb readings may reach as high as 85° F. and the place may be rated comfortable. With a wet bulb above 85° F., a place to be comfortable must have rapid movement of air 500 linear feet per minute or over, or a comparatively low humidity, less than 80 per cent, or both. Out of 78 places in this mine rated comfortable, 63, or 81 per cent, had a wet-bulb temperature less than 80° F.; out of 80 places rated uncomfortable but 22, or 27½ per cent, had a wet bulb less than 80° F.; and only 2 places, or 2½ per cent, had a wet bulb less than 75° F. The dividing line between comfortable and uncomfortable places seems to be between 75° or 80° F., wet bulb.

DRY-BULB TEMPERATURE.

As with wet-bulb readings, the line between comfortable rating and uncomfortable rating seemed to fall between 75° and 80° F., though places were rated comfortable with much higher dry-bulb readings than wet-bulb readings, for with wet-bulb readings the movement of air seemed to have more influence on comfort than the temperature until the latter approached 90° F.

RELATIVE HUMIDITY.

Table 22 shows that out of 69 stopes visited, but one had a relative humidity less than 85 per cent, this one being on the first floor directly above a drift serving as the main air course and only a short distance from the downcast shaft. There was also but one raise with a relative humidity less than 85 per cent, and in this raise two compressed-air stopers had been working steadily for some time. Both of these places were rated comfortable. Of the entire 158 places in the mine, only 22 had a relative humidity less than 85 per cent, 21 being rated comfortable; but 34 out of the 158 places had a relative humidity less than 90 per cent, and of these 8 were rated uncomfortable. Of 51 places with a relative humidity between 90 and 95 per cent, 25 were rated comfortable and 26 uncomfortable; of 73 places with a relative humidity of 95 per cent or over, 46 were uncomfortable; this seems to indicate that relative humidity is a de-

cisive factor only when it exceeds 95 per cent. Table 22, however, shows that 10 out of 16 drifts and 8 out of 11 crosscuts with relative humidity over 95 per cent were rated comfortable; and Tables 17, 18, 19, and 20 indicate that even with a relative humidity of 95 per cent or over, places with fair or good air velocity were rated comfortable even when high humidity was accompanied with temperatures between 85° and 90° F. Humidity above 95 per cent, even unaccompanied by air movement, may permit a place to be rated as at least fairly comfortable if the temperature is less than 80° F.

AIR MOVEMENT.

An inspection of Tables 14 and 16 shows that in mine A, one of the best ventilated in the Butte district, there were but 71 out of 158 places credited with a fair air movement, and of these but 42, or 26.5 per cent of all, had a good movement; 29, or 18.3 per cent, having only slight movement. Only 8 stopes out of 69, or less than 12 per cent, had a good movement—100 linear feet per minute or over; and 13 places more, or less than 20 per cent, had light movement, discernible with a candle flame.

Only 2 raises out of 18, or 11 per cent, had good air movement. One of these had broken through to the level above and the other had circulating air on the twelfth floor from the end of a canvas pipe with a fan on the level below. Of 40 places in drifts, 18 had good air circulation, 3 slight circulation, and 19 no circulation. Twenty of the 40 places in drifts were at the face, the other 20 being on haulage roads, etc., and usually in a main air current. Fourteen places in crosscuts had good circulation, 13 had slight movement, and 4 had no air movement. Eight of the thirty-one places were at the face, the remainder being generally in main air currents.

Of 20 stopes rated comfortable (Table 17), 11 were those with fair air circulation; 5 of the remaining 9 had temperature less than 65° F., and the other 4 had temperatures less than 75° F. Of 49 stopes rated uncomfortable, 7 had slight air movement and 3 had fair movement. The entire 12 raises rated uncomfortable had absolutely no discernible air movement; of the 6 raises rated comfortable, 2 had fairly good air movement, 1 had a temperature less than 65° F., and the other 3 with temperatures between 75° and 80° F. and no air movements were rated only fairly comfortable or on the border between comfort and discomfort.

Of 26 drifts rated comfortable, 18 had good air movement; and 6 of the remaining 8 comfortable places had temperatures of 65° F. or less, the other 2 places being rated fairly comfortable. Of the 26 comfortable drifts, readings were made at the breast in 10, 6 having temperatures of 65° F. or less and no air movement; 2 drift breasts

had good air movement because of a small fan and canvas pipe, and 2 without air movement were rated fairly comfortable. Of the 14 drifts rated uncomfortable, 3 had slight air movement, with temperatures between 80° and 85° F., and 10 of the 14 were at the breast.

Of 26 comfortable crosscuts, 25 had adequate air movement, the one place without air movement having a temperature of 75½° and being rated fairly comfortable. Only 5 of these 26 comfortable crosscuts were at the face; hence, in general, readings were taken where men were working in main air currents. Of five crosscuts called uncomfortable, two had a slight air current with high relative humidity and a temperature around 85° F.; in three of the five uncomfortable crosscuts the readings were at the face.

DISCUSSION OF DATA FROM MINE A.

From the above discussion it appears that in places with temperature below 75° F. a man feels comparatively little discomfort even when the relative humidity approaches 100 per cent and there is practically no movement of air. In such places, however, discomfort manifested by headache, shortness of breath, and extreme readiness of perspiration, may be expected when the air becomes depleted of 1 per cent or more of oxygen, or when the percentage of CO₂ increases to 0.30 per cent or over, or when explosives fumes or smoke hang at the face or in the muck pile.

With temperatures, especially wet bulb, between 75° and 80° F., places without air circulation are likely to be uncomfortable as manifested by excessive perspiration, possibly headache, dizziness, occasional nausea, frequent mental dullness, and almost invariably by a rising bodily temperature with even slight manual labor; if the relative humidity is high, the ill effects are accentuated, and a very small amount of fumes from explosives soon indicates itself. A fair movement to such air, 100 linear feet per minute, or over, gives immediate relief.

With temperatures between 80° and 90° F., a feeling of extreme oppression is felt in stagnant underground air, even when the relative humidity is low; and very small amounts of CO₂, from 0.10 per cent up, or a very slight oxygen depletion, 0.50 per cent or over, quickly show themselves in depressing the worker, increasing perspiration, raising bodily temperature, and lowering blood pressure. On the other hand, air of the above temperature and humidity, but with velocity of four or five hundred feet or more per minute, had little or no ill effect as far as could be observed. Moreover, air with good movement and with temperature of 80° to 90° F. was by no means oppressive even when its relative humidity approached 100 per cent, or had about 0.25 per cent CO₂ or as little as 19.5 per cent oxygen.

With temperatures of 90° to 95° F., particularly wet-bulb temperatures, stagnant air even when pure and of low relative humidity is very oppressive, yet such air with a velocity of 500 or more feet per minute is endurable, especially if its relative humidity is below 85 per cent. A relative humidity less than 98 per cent does not appear to be particularly harmful until temperatures rise above 90°, provided there is ample movement of air, and the writer believes that at temperatures as high as 95°, or about 3° less than normal bodily temperature, air of high velocity, such as is obtained from the canvas-pipe fan units coming into use in Butte, will provide comfortable working conditions even should the relative humidity also be as high as 98 per cent.

USE OF SMALL FANS TO FORCE AIR THROUGH CANVAS TUBING.

Table 10 shows that 1 out of the 5 comfortable stopes, 1 out of 2 comfortable raises, 1 out of 18 comfortable drifts, and 7 out of 14 comfortable crosscuts had good air movement due to a small fan forcing air through canvas tubing; hence 10 out of the 78 comfortable places had air movement due to these small fan units, and of 39 places rated comfortable and having good air movement, 10 owed that good air movement to such units, these places being at working faces in blind ends which so frequently are wholly without fresh air. Figures 16, 17, 18, 22, 23, 25, and 26 give data as to the increase of temperature, the decrease of humidity, and the velocities, in dry canvas tubing; they also indicate possible methods of controlling the increase of temperature. Plate II, A, shows a small fan and a canvas pipe in a drift.

Figure 38 gives data showing the effect of transmitting air through canvas pipe to a breast with a rock temperature of 91°, and an air temperature of approximately 91° F.; the canvas tubing delivered air at 77½° F. and 96 per cent relative humidity to a man mucking 15 feet from the breast, where he was able to work in comfort; yet 15 feet distant, at the breast but out of the air stream, the temperature was 88° F., the relative humidity 91 per cent, and the effect was markedly uncomfortable.

Besides showing the efficiency of fans and canvas tubing in ventilating blind ends, Figure 38 also shows how carelessness in not keeping the air stream directed to the exact working place may nullify entirely the efficiency of the fan and canvas pipe. In one drift ventilated by canvas tubing the end of the tubing was 50 feet from the breast and the air stream was so directed that the current hit the back within a few feet, was deflected to the floor, and turned outward about 20 feet from the breast; a mucker at the breast was shoveling dry material in a smoky, stagnant atmosphere, and complaining of headache and

nausea; the cause of the man's discomfort was removed readily by lowering the end of the canvas pipe a trifle and by directing the air toward the breast.

Failure to keep the end of the ventilating pipe close enough to the breast also results in inefficient ventilation. Figures 39 and 40 show air rapidly loses velocity in traveling 60 feet to the breast, having practically no velocity at the breast though leaving the end of the pipe at 5,000 linear feet per minute. On the other hand, Figures 13 and 14 show that with the end of the canvas pipe only 20 feet from

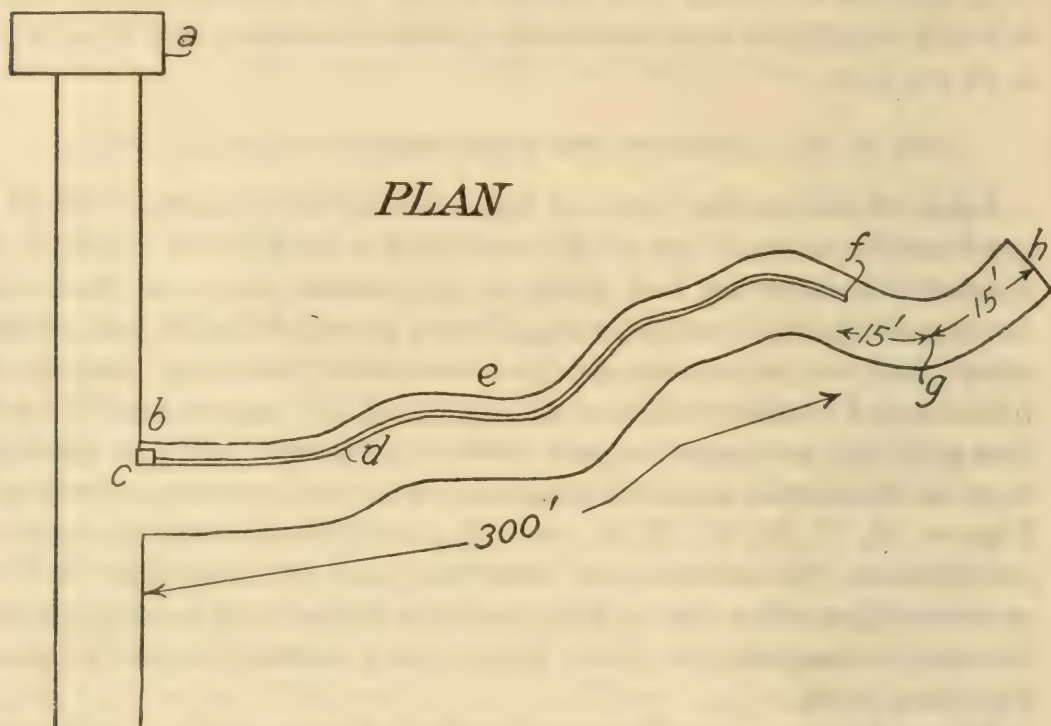


FIG. 38.—Effect of transmitting air by canvas pipe to a hot working place: *a*, 3,000-ft. station, downcast shaft, 61° F. wet bulb, 61½° F. dry bulb, 97 per cent humidity; *b*, No. 2½ fan; *c*, 68° F. wet bulb, 71° F. dry bulb, 68 per cent humidity; *d*, 10-inch canvas pipe; *e*, drift; *f*, 71° F. wet bulb, 77½° F. dry bulb, 76 per cent humidity; *g*, 76° F. wet bulb, 77½° F. dry bulb, 96 per cent humidity, muck pile here; *h*, 81° F. wet bulb, 88° F. dry bulb, 91 per cent humidity, 12-inch hole in back gave rock temperature of 91 per cent humidity.

the face of a drift, the velocity at the face was well over 300 feet per minute, though the issuing velocity at the end of the pipe was only a trifle over 4,000 feet per minute. Where canvas tubing is used in levels, it can easily be kept within 50 feet of the face, as a 25 or 50 foot length is easily removed before blasting, not over 5 or 10 minutes of one man's time being required.

Figure 41 shows results of experiments with canvas-pipe ventilation of a raise; although air was delivered at 81° dry bulb on the eleventh floor of this raise, the relative humidity was but 63 per cent; at the point where drillers were working on the twelfth floor, the

dry-bulb temperature was 83° and the humidity 76 per cent. This working place was the most comfortable of all those in raises in the entire 25 or more mines visited in Butte; these men were able to work steadily and drove the raise rapidly without a bonus—a very desirable result, as it is becoming increasingly difficult to obtain men to drive raises in the deeper levels, because they know that such work under old conditions will inevitably shorten their lives.

Figure 42 gives data on fan and canvas-pipe ventilation of cross-cuts driven in solid granite in levels below the 3,000, with natural

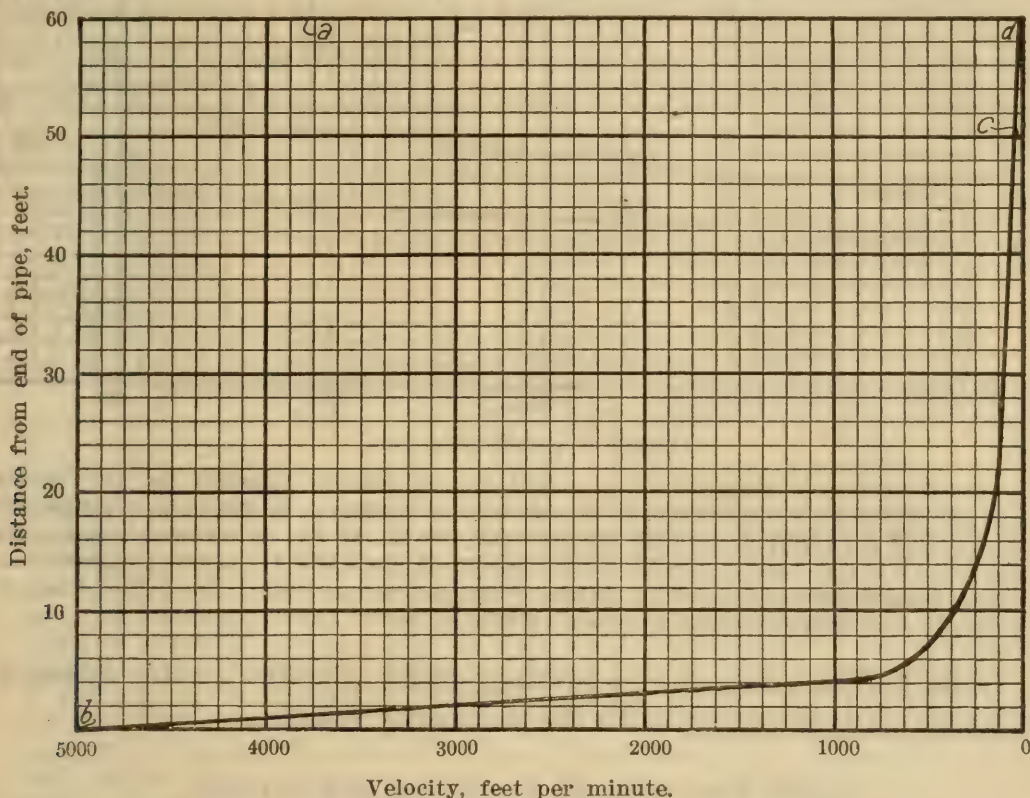


FIG. 39.—Decrease of velocity of air after leaving pipe: *a*, Face of drift; *b*, end of canvas pipe, air 79° F. wet bulb, 83° F. dry bulb, 84 per cent rel. hum.; *c*, velocity approximately 50 ft. a min.; *d*, air at breast 80° wet bulb, 83° dry bulb. Used 400 ft. of 16-inch canvas pipe taking air at 77° F. wet bulb, 79° F. dry bulb, 91 per cent rel. hum., and discharging it at 79° F. wet, 83° F. dry bulb, 84 per cent rel. hum. Had a $7\frac{1}{2}$ -h. p. motor and a No. 6 fan with 16-inch diam. intake and 12-inch discharge. (See also Figure 40.)

rock temperatures 100° F. or higher. Although the natural rock temperatures were 100° F. or over, the use of a fan and canvas pipe allowed the men working two shifts to be in moving air with temperatures 85° F., or less, giving them such good conditions that they drilled a 13 or 14 hole round daily and removed the blasted material, advancing the 5 by $7\frac{1}{2}$ foot crosscut $4\frac{1}{2}$ feet daily through hard granite. These places, moreover, were driven at the same price per foot as in upper, cooler levels. If there had been no ventilation other than compressed air, the men undoubtedly would have been working in practically still air with temperatures of 100° F. or over and a

humidity of practically 100 per cent; such conditions would have permitted not more than one-third to one-half efficiency, and the miners would have demanded a substantial bonus. In sinking the shaft from which these crosscuts were driven, progress was made at the rate of 50 feet one month and 60 feet another, but was increased to 130 feet per month after the installation of a fan and canvas pipe.

In addition to experiments with the fan and canvas-pipe system

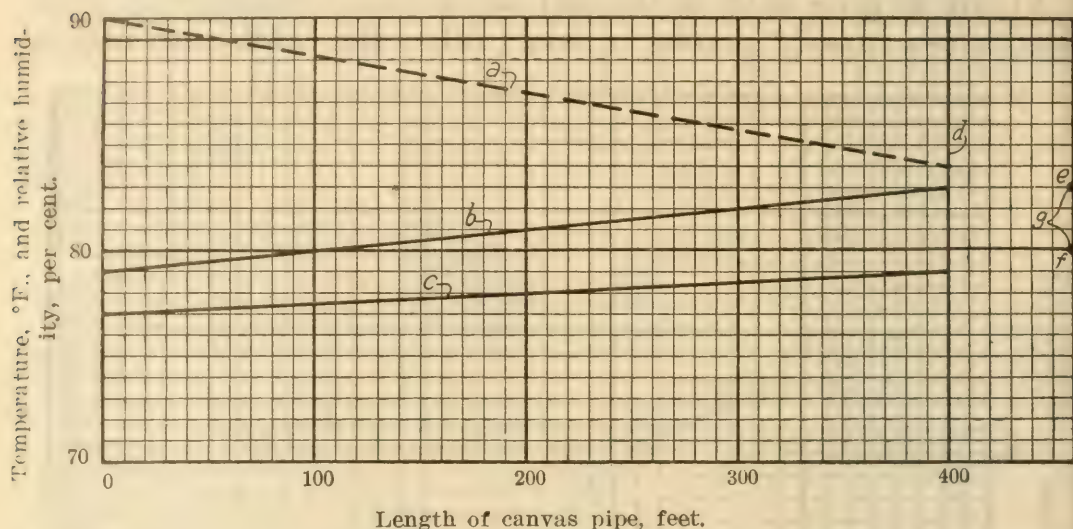


FIG. 40.—Increase of temperature and decrease of relative humidity in air flowing through canvas pipe (see Figure 39 for decrease of velocity) : *a*, Rel. hum. decrease per 100 ft. 1.75 per cent; *b*, dry-bulb increase per 100 ft., 1° F.; *c*, wet-bulb increase per 100 ft., $\frac{1}{2}$ ° F.; *d*, end of canvas pipe, velocity of air 5,000 ft. a min.; *e*, rock and breast temperatures, dry bulb; *f*, breast temperature, wet bulb. No. 6 fan, 7½-h. p. motor, 11-inch intake, 12-inch exhaust, velocity of motor 1,700 r. p. m.

in drifts and in crosscuts, in sinking shafts, and in driving raises, a trial was made in stopes, with the following results:

Results from using fan and canvas pipe in stopes.

Date.	Place.	Wet bulb.	Dry bulb.	Relative humidity.	Remarks.
		° F.	° F.	Per ct.	
Dec. 7, 1916	First floor of stope.....	78½	80	94	No air movement, very uncomfortable.
Jan. 9, 1917	do	75	84	66	Moving air, entirely comfortable.

The rock temperature was 87° when the stope reached the fourth floor. When a cool water spray, as pictured in Figure 25, was introduced into the intake the air entered the stope on the fourth, fifth, and sixth floors at temperatures of 70° wet bulb and 73° dry bulb, a relative humidity of 86 per cent, and was very comfortable. This stope was one of the very few comfortable ones in this vein in the entire mine. Though the reading on January 9, 1917, gave a dry-bulb temperature of 84° in the air issuing from the dis-

charge end of the canvas pipe, as against 80° dry bulb in the stagnant air before the canvas pipe was placed, the improvement effected by the moving current of air with low humidity was remarkable.

As a demonstration of the coolness and comfort of warmer moving air as against still air, the investigators had the following experience in one Butte mine: Men who were working in a stope, in still air with a wet-bulb temperature of 76°, dry bulb 79°, and a relative humidity of 86 per cent, were accustomed to walk about 50 feet to the level above to cool off, though the air in the drift had temperatures of 80° wet bulb, 82° dry bulb, and a relative humidity of 91 per cent, or 4 degrees higher wet-bulb temperature and 5 per cent greater relative humidity than the air in the stope they had left. The

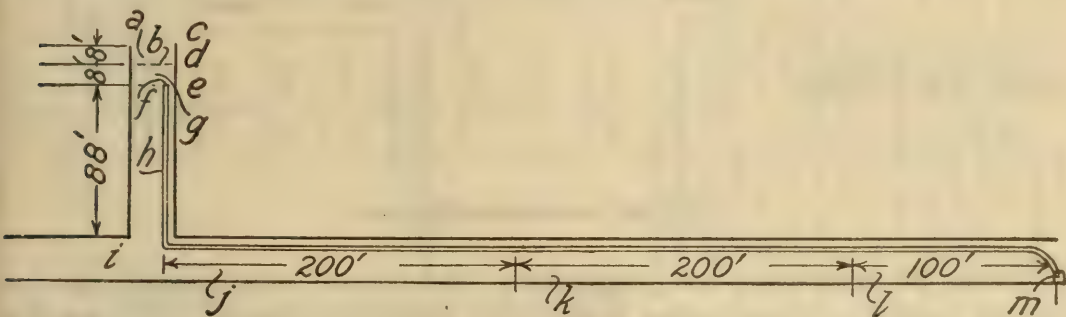


FIG. 41.—Ventilation of a high raise by fan and canvas pipe: *a*, Rock temperature in upper hole 86° F.; *b*, air, 76° F. wet bulb, 83° F. dry bulb, 76 per cent rel. hum., good movement; *c*, back, 13th floor approximately; *d*, 12th floor; *e*, 11th floor; *f*, wire screen over end of canvas pipe; *g*, air at end of pipe, 71½° F. wet bulb, 81° F. dry bulb, 63 per cent rel. hum., velocity 4,000 ft. a min., volume 1,400 cu. ft. a min.; *h*, 8-inch canvas pipe, boxed; *i*, air in drift, 81° F. wet bulb, 82° F. dry bulb, 91 per cent rel. hum.; *j*, damp drift, 81° F. wet bulb, 82° F. dry bulb, 91 per cent rel. hum.; *k*, wet drift, 82° F. wet bulb, 85° F. dry bulb, 96 per cent rel. hum.; *l*, dry drift, 68° F. wet bulb, 72° F. dry bulb, 81 per cent rel. hum.; *m*, No. 2½ fan, intake air 68° F. wet bulb, 72° F. dry bulb, 81 per cent rel. hum. Practically 600 ft. of 8-inch canvas pipe with one 90° galvanized pipe elbow and two 45° elbows, there were 13 turns each over 30° in the drift. Dry-bulb temperature increased 9° F. and rel. hum. decreased 18 per cent.

air in the drift, however, was moving at the rate of 150 linear feet per minute; that in the stope was stagnant, and a distinct feeling of relief was felt on entering the warmer air in the drift.

DAMPNESS.

Table 15 (p. 79) presents data regarding the dampness and dryness of working places in mine A. A place was rated damp if the surrounding walls were wet or damp, or if the muck pile at the face was damp or wet from natural moisture. Few if any places were wet enough to require the use of rubber coats or hats, and in few places rubber boots were needed. Out of 158 places, 45, or 28.5 per cent, were rated damp, and this proportion held roughly for all classes of working places, except raises, only 2 out of 18 of which were damp.

It seems that the degree of dampness has comparatively little effect on comfort, as the damp places generally had low temperature also, or had good air movement. For instance, of 7 damp stopes, also rated comfortable, all had a temperature of 75° F. or less; 7 out of 12 damp drifts rated comfortable had a temperature of 75° F. or less, and all the 8 damp crosscuts rated comfortable had adequate air movement.

TABLE 23.—*Use of compressed air in mine A.*

	Stopes.		Raises.		Drifts.		Crosscuts.		Com- fort- able.	Un- com- fort- able.	Total.
	Com- fort- able.	Un- com- fort- able.	Com- fort- able.	Un- com- fort- able.	Com- fort- able.	Un- com- fort- able.	Com- fort- able.	Un- com- fort- able.			
Compressed air blowing.....	9	36	3	9	4	6	6	2	22	53	75
Compressed air not blowing.....	11	13	3	3	22	8	20	3	56	27	83
Total.....	20	49	6	12	26	14	26	5	78	80	158

USE OF COMPRESSED AIR.

Table 23 contains data regarding the use of compressed air in stopes, raises, crosscuts, and drifts; out of 78 comfortable places only 22, or less than 28 per cent, were using compressed air, and 53 out of 80 uncomfortable places, or over 66 per cent, were using it. The consumption of compressed air in the comfortable places, therefore, was less than half that of the uncomfortable ones, and the use of the compressed air failed entirely to give comfort beyond a very narrow zone. Figure 27 shows data compiled from many readings of the temperature and humidity of compressed air and the ordinary mine air on several levels. Though the relative humidity of the compressed air at the end of the hose is low, 5 feet from the end of the hose the humidity of the air stream is essentially that of the surrounding air; similarly, though the dry-bulb temperature of the compressed air at the end of the hose is 1 to 5° F. lower than that of the surrounding mine air, the difference is generally less than 1° F. after the stream of air has traveled 5 feet. Hence, little benefit is to be gained from the use of compressed-air blowers for cooling or drying except near the end of the hose. In upper levels the compressed air is frequently warmer than the mine air. The chief benefits from using compressed air are the slight movement given the air in the working place and the introduction of comparatively fresh air. The amount of compressed air released by the ordinary blower averages slightly over 100 cubic feet of free air per minute; if the valve were opened wide and the pressure were 80 pounds or over the amount would reach nearly 200 cubic feet per minute.

In a stope with a cross-sectional area of about 25 square feet per open set, and frequently with six to ten sets open, the velocity of this 200 cubic feet of air released per minute might be much less than

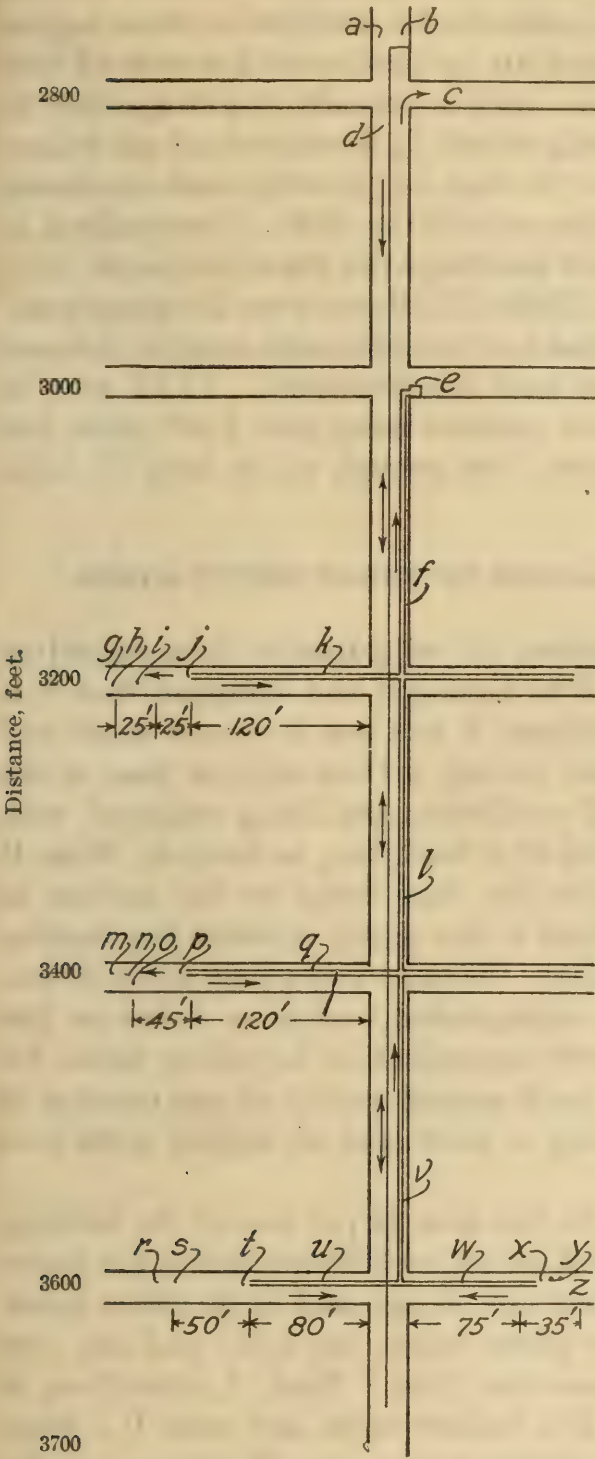


FIG. 42.—Ventilation with fan and canvas pipe in deep workings with rock temperatures of 100° or higher: *a*, Main compartment; *b*, chippy compartment; *c*, return air from 3,200, 3,400, and 3,600 levels; *d*, air, 62½° F. wet bulb, 65° F. dry bulb, 67 per cent rel. hum.; *e*, No. 6 fan, 30-h. p. motor, forces air to 3,200, 3,400, and 3,600 levels through canvas pipe, air 61° F. wet bulb, 61½° F. dry bulb, 97 per cent rel. hum.; *f*, box 24 by 24 in.; *g*, rock temperature, end of 51-inch hole, 100° F. water used in Leyner drill 75° F.; *h*, air 76° F. wet bulb, 82° F. dry bulb, 76 per cent rel. hum.; *i*, air, 70½° F. wet bulb, 78° F. dry bulb, 69 per cent rel. hum.; *j*, 65° F. wet bulb, 72° F. dry bulb, 69 per cent rel. hum.; *k*, 12-inch canvas pipe; *l*, 16-inch canvas pipe; *m*, rock temperature 102° F. in 3 to 5 ft. holes; *n*, air with canvas pipe in place, 77° F. wet bulb, 83° F. dry bulb, 76 per cent rel. hum.; *o*, air 20 min. after fan had stopped, 80° F. wet bulb, 86° F. dry bulb, 77 per cent rel. hum.; *p*, air at end of canvas pipe, 65° F. wet bulb, 74° F. dry bulb, 62 per cent rel. hum.; *q*, 12-inch canvas pipe; *r*, rock temperature, 104° F.; *s*, air at face, 82½° F. wet bulb, 85° F. dry bulb, 90 per cent rel. hum.; *t*, air at end of canvas pipe, 67° F. wet bulb, 74½° F. dry bulb, 68 per cent rel. hum., velocity 3,800 ft. a min., volume 3,000 cu. ft. a min.; *u*, 12-inch canvas pipe; *v*, 16-inch canvas pipe; *w*, 10-inch canvas pipe; *x*, air, 67½° F. wet bulb, 73½° F. dry bulb, 73 per cent rel. hum., velocity 4,600 ft. a min.; *y*, water drippers 100° F.; *z*, air, 81½° F. wet bulb, 83° F. dry bulb, 90 per cent rel. hum. Shaft downcast to 3,000 ft. in main compartments and to 2,600 ft. in chippy compartments; neutral as to main compartments from 3,000 to 3,700 ft. and upcast in chippy compartments from 3,700 to 2,800 ft.

1 foot per minute through the stope, and would seldom reach more than 5 to 10 feet per minute, hence compressed air moves explosive fumes very slowly from the working faces, even from crosscuts, drifts, and raises, generally with a cross-sectional area of 30 to 45

square feet. As against the 100 cubic feet or so of air obtainable from existing blowers, 1,000 to 10,000 cubic feet per minute can be obtained by using small fans and canvas or galvanized-iron pipe, or by bratticing as in coal mining.

Compressed-air blowers are inefficient for ventilation; their aggregate consumption of compressed air is heavy and the cost of this air is great. A compressed-air drill is actually working—that is, consuming compressed air—only about $1\frac{1}{2}$ hours out of an 8-hour shift, or less than 20 per cent of the time, but a compressed-air blower is generally in use at least 75 per cent of the shift. Frequently it is in use the entire shift and is left blowing after the shift leaves.

Out of 158 places visited (Table 23) there were 75 using compressed air. As the visits covered a period of several months, it is not known how many blowers were used simultaneously. If all were in use at the same time they would consume more than 7,500 cubic feet of air per minute, or much more than enough air to keep 75 drills in operation.

COMPARISON OF VENTILATION IN THREE BUTTE MINES.

Table 24 contains a summation of comparative data regarding mines A, B, and D. Mine A is so arranged and equipped that it is entirely capable of self-ventilation; it has one downcast shaft and three upcasts, two of the latter having surface suction fans at the surface and one using natural ventilation but being equipped with a fan for use either as a suction or a force fan, as desired. Mine B has chiefly force-fan ventilation, the fans being on the surface at shafts of adjoining mines. Mine D has partly exhaust-fan ventilation and partly natural ventilation. In mine B is a long-existent, live fire; in D is a fire practically extinguished, and mine A has no fire. Both B and D are at least partly dependent on adjoining mines for ventilation. All three mines work several veins; all are capable of producing 1,000 tons of ore a day or more, and all employ more than 300 men per shift.

Mine A, as shown in Table 24, has over 82 per cent of its working places below the 2,000-foot level, where rock temperatures are necessarily high. Mine B has slightly over 47 per cent of its places below the 2,000-foot, mine D has no places below the 2,000 and has over 50 per cent of its places above the 1,000. Mine A, therefore, is essentially a deep mine, mine D a shallow mine, and mine B a mean between the two. In the two deeper mines, over 70 per cent of the places were rated dry; in the shallow mine only 43 per cent of the places were dry, and 9.1 per cent were not rated as to dampness. The average dry bulb temperature of all places in the deep mine A was 78.8° F. as against 77.4° F. for the shallow mine D, and 82.5°

F. for the medium mine B. This record shows the efficient ventilation of mine A, the average temperature of its places being 3.5° below that of mine B, and within 1.4° F. of the average of all readings in Mine D, which had no places below the 2,000 and over 50 per cent above the 1,000. In mine A $82\frac{1}{2}$ per cent of the places were below the 2,000-foot level where the original rock temperatures are over 85° F., and 35 per cent of its places were below the 2,500, where original rock temperatures stand between 95° and 104° F. It is significant that in mine A 44.9 per cent of the places had fair air movement as against 25.3 per cent in mine B and 36.4 per cent in mine D; moreover, though velocities of 400 linear feet per minute were frequently found in the main air courses of mine A and occasionally in mine B, they were very seldom found in mine D.

TABLE 24.—*Summation of data relative to ventilation in mines A, B and D.*

	Mine A.										Mine B.										Mine D.																
	Stopes.		Raises.		Drifts.		Cross-cuts.		Entire mine.		Per cent		Stopes.		Raises.		Drifts.		Cross-cuts.		Entire mine.		Per cent		Stopes.		Raises.		Drifts.		Cross-cuts.		Entire mine.		Per cent		
	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.	° F.	No.			
																																			° F.	No.	° F.
Wet bulb.....	79.2	69	80.2	18	74.2	40	72.7	31	76.8	158	.....	76.4	47	83.8	11	76.8	19	76.4	10	77.8	87	.....	74.1	38	77.9	13	72.6	19	77.2	7	74.5	77	.....	77	.....	77	
Dry bulb.....	80.6	69	81.7	18	76.7	40	75.5	31	78.8	158	.....	79.8	47	87.8	11	81.1	19	82.5	10	82.5	87	.....	76.8	38	80.0	13	75.8	19	79.7	7	77.4	77	.....	77	.....	77	
Relative humidity.....	93.9	69	93.7	18	90.0	40	85.5	31	91.3	158	.....	86.8	47	86.3	11	84.5	19	85.2	10	85.2	87	.....	87.3	38	91.0	13	85.4	19	89.6	2	87.7	77	.....	77	.....	77	
Wet bulb under 75° F.....	10	59	.....	17	1	14	.....	15	40	26.1	.....	11	36	.....	0	6	.....	21	24.2	4	.....	21	24.2	.....	15	2	.....	12	.....	2	.....	31	40.3	.....	31	40.3	
Wet bulb over 75° F.....	59	.....	.....	17	26	.....	16	.....	118	73.9	.....	36	.....	11	.....	13	.....	66	75.8	6	.....	66	75.8	.....	23	11	.....	7	.....	5	.....	46	59.7	.....	46	59.7	
Relative humidity under 85 per cent.....	1	.....	.....	1	8	.....	12	.....	22	13.9	.....	12	.....	2	.....	7	.....	28	32.2	7	.....	28	32.2	.....	10	1	.....	6	.....	2	.....	19	24.7	.....	19	24.7	
Relative humidity over 85 per cent.....	68	.....	.....	17	32	.....	19	.....	136	86.1	.....	35	.....	9	.....	12	.....	59	67.8	3	.....	59	67.8	.....	28	12	.....	13	.....	5	.....	58	75.3	.....	58	75.3	
Compressed air blowing.....	45	.....	.....	12	10	.....	8	.....	75	47.5	.....	22	.....	9	.....	7	.....	43	49.4	5	.....	43	49.4	.....	10	8	.....	4	.....	3	.....	25	32.5	.....	25	32.5	
Compressed air not blowing.....	24	.....	.....	6	30	.....	23	.....	83	52.5	.....	12	.....	1	.....	1	.....	23	26.9	2	.....	23	26.9	.....	6	2	.....	6	.....	2	.....	16	20.8	.....	16	20.8	
No record as to compressed air.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	13	.....	1	.....	4	.....	21	24.2	3	.....	21	24.2	.....	22	3	.....	9	.....	2	.....	36	46.7	.....	36	46.7	
Air movement fair (slight or good).....	21	.....	.....	2	21	.....	27	.....	71	44.9	.....	14	.....	0	.....	7	.....	22	25.3	1	.....	22	25.3	.....	18	0	.....	9	.....	1	.....	28	36.4	.....	28	36.4	
Air movement, none.....	48	.....	.....	16	19	.....	4	.....	87	55.1	.....	28	.....	11	.....	9	.....	57	65.5	9	.....	57	65.5	.....	5	11	.....	10	.....	5	.....	31	40.3	.....	31	40.3	
Air movement, no record.....	18	.....	.....	2	16	.....	9	.....	45	28.5	.....	5	.....	0	.....	3	.....	8	9.2	0	.....	8	9.2	.....	15	2	.....	0	.....	1	.....	18	23.3	.....	18	23.3	
Damp places.....	51	.....	.....	16	24	.....	22	.....	113	71.5	.....	11	.....	1	.....	7	.....	20	23.0	1	.....	20	23.0	.....	17	2	.....	5	.....	3	.....	27	35.1	.....	27	35.1	
Dry places.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	34	.....	10	.....	9	.....	62	71.3	9	.....	62	71.3	.....	17	9	.....	14	.....	3	.....	43	65.8	.....	43	65.8	
No record as to dampness.....	9	.....	.....	2	7	.....	1	.....	19	12.5	.....	2	.....	2	.....	4	.....	5	5.7	0	.....	5	5.7	.....	4	2	.....	0	.....	1	.....	7	9.1	.....	7	9.1	
Places above 1,000-foot level.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	10	.....	2	.....	2	.....	19	21.8	3	.....	19	21.8	.....	19	7	.....	10	.....	3	.....	39	50.6	.....	39	50.6	
Places between 1,000-foot and 2,000-foot levels.....	3	.....	.....	0	4	.....	1	.....	8	5.0	.....	14	.....	2	.....	7	.....	27	31.0	4	.....	27	31.0	.....	19	6	.....	9	.....	4	.....	38	49.4	.....	38	49.4	
Places below 2,000-foot level.....	57			16	29		29		131	82.5		23		7		8		41	47.2	3		41	47.2		0	0		0		0		0		0		0	
Comfortable places.....	20			6	26		26		78	49.4		16		0		8		28	32.2	4		28	32.2														
Uncomfortable places.....	49			12	14		5		80	50.6		27		11		11		53	60.9	4		53	60.9														
No record as to comfort.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4	.....	0	.....	0	.....	6	60.9	2	.....	6	60.9	.....	38	13	.....	19	.....	7	.....	77	.....	77	.....	77	

Mine A had an average relative humidity of 91.3 per cent as against 85.2 per cent for mine B and 87.7 for mine D; 86.1 per cent of the places in mine A had a relative humidity over 85 per cent, against only 67.8 per cent in mine B, and but 75.3 per cent in mine D. In mine A 73.9 per cent of the places had wet-bulb temperatures over 75° F., in mine B, 75.8 per cent, and in mine D only 59.7 per cent. Mine A had 49.4 per cent of its 158 places rated comfortable, as against 32.2 per cent of the 87 places in mine B. Rating as to comfort had not begun when mine D was examined.

Mines A, B, and D are typical of the conditions found in the best equipped and operated mines of the Butte district, and the data given may be said to represent the best practice there. Mine A has deep and extensive workings and high rock temperatures, but it has its own system of ventilation, including adequate reversible fans, up-cast and downcast shafts, auxiliary distributing fans, and canvas pipe, and, in consequence, has a comparatively large number of comfortable working places and a comparatively low average temperature. In the opinion of the writer, therefore, it is the best ventilated and one of the most efficiently operated mines in the district. Mines B and D represent the best of the general type of Butte mines with shallow or medium-depth workings, depending in part, at least, on adjoining mines for air circulation, and with partly natural and partly mechanical ventilation. It hardly seems advisable to criticize in detail the numerous very poorly ventilated mines in the district, as the writer believes more can be accomplished by drawing attention to the deficiencies of the best ventilated mines. Such deficiencies, of course, exist in the poorly ventilated mines in a much aggravated degree.

EXPERIMENTAL WORK ON AIR FLOW IN BUTTE MINES.

Important data were obtained from Butte mines relative to the air flow. Some of the mining companies have devoted much time and attention to the subject. Much experimental work has been done to ascertain how the smooth-lining of shafts affects the velocity and volume of air. One of the deepest shafts in the district was smooth-lined to the 3,000-foot level, partly by boards and gunite, partly by solid concreting; with the same ventilating equipment the air flow was increased from 55,000 to about 85,000 cubic feet per minute by the smooth-lining.

In another mine an air shaft 2,800 feet deep, with two compartments 5 by 5 and one compartment 5 by 7 feet, a total cross section of 85 square feet, with an ordinary lining of exposed timber, passed 115,000 cubic feet of air per minute at 3.4-inch water gage to a fan driven by a 150-horsepower motor. Subsequently the 5 by 7

compartment was smooth-lined and the same fan equipment exhausted through this compartment 128,000 cubic feet per minute at 3.1-inch water gage. The air velocity in the shaft was a trifle over 1,350 linear feet per minute, but more than 3,650 feet per minute in the one smooth-lined compartment. A larger fan with 200-horsepower motor was placed at the shaft collar and connected to the two 5 by 5 foot compartments, which had not been smooth-lined, the fan with the 150-horsepower motor remaining in place and pulling from the 5 by 7 smooth-lined compartment. The smaller fan pulled 114,000 cubic feet per minute at 3.2 inches water gage through the one 5 by 7 smooth-lined compartment, whereas the larger fan pulled 92,000 cubic feet per minute at 3.9 inches water gage through the two rough-lined 5 by 5 compartments. The two fans pulled air from the same sources, yet the velocity in the smooth-lined compartment was over 3,250 linear feet per minute, and in two rough compartments was only about 1,840 feet per minute, the smaller fan producing the greater velocity. Before any smooth lining had been done in the shaft the smaller fan working alone pulled 115,000 cubic feet per minute at 3.4-inch water gage through the entire shaft; the larger fan, also working alone, pulled 135,000 cubic feet per minute at 3.5-inch water gage through the entire shaft.

At another mine three shaft models, on a scale of about three-fourths inch to a foot, were constructed, one an exact reproduction of the usual timbered rectangular Butte shaft; the second differed only in having the interior covered with boards to make it smooth; the third model was of solid concrete, with smooth interior surface and circular cross section. The three models were each about 150 feet long and had the same interior cross-sectional area. They were placed side by side in an underground raise, with a small fan that could be connected through a flexible hood to the top of each to pull air through it. Tests showed that if the volume of air that can be pulled through the usual timber-lined rectangular section model be represented by 1, the same power will pull 1.91 volumes through the smooth-lined rectangular shaft, and 3.31 volumes through the smooth-lined circular section shaft. The water gages were 3.2, 2.7, and 2.1; the power ratio for equal volumes of air pulled were as 1.00, 0.277, and 0.091, and the frictional coefficients were 0.000,000,005,37; 0.000,000,001,47; and 0.000,000,001,14.

Several methods of smooth-lining have been tried in Butte shaft construction, being as follows: (1) Solid concrete, the smooth-lining being only incidental; (2) usual rectangular type, with fire-proof slabs, made on the surface, fastened to the timbers; (3) planks attached to the timbers and then covered with chicken wire or metal lath and "gunited"; and (4) burlap and chicken wire stretched



A. SMALL FAN AND CANVAS PIPE IN A DRIFT.



B. DEFLATED CANVAS PIPE IN AN UNTIMBERED CROSSCUT.



ASPHALT-TREATED CANVAS PIPE VENTILATING A RAISE.



CANVAS PIPE UNDER PRESSURE TURNING A CORNER IN A TIMBERED DRIFT.

over the exposed shaft timbers and gunited. Costs ran from \$8 or \$10 to as high as \$20 per linear foot of the three-compartment shaft, which was 5 by 17 or 18 feet.

Other experimental work was done often by Butte mining companies in cooperation with manufacturers. Tests showed that canvas tubing had many advantages over galvanized pipe for blowing air to blind ends, using small direct-connected electric motors and blowers. The stock sizes of blowers, however, handled more air than the desired sizes of canvas pipe could transmit; by decreasing the width of stock sizes of small blowers to one-third or one-half or two-thirds smaller motors could be used to transmit the same quantity of air through the canvas tubing. By adopting the smaller motors and blowers of less width the consumption of power was decreased at least 30 per cent.

Canvas pipe, though very flexible, had many disadvantages. One disadvantage was overcome by one of the mine managers inventing an efficient method of coupling the lengths of canvas pipe and a cheap and simple method of suspending the pipe. Other and more serious disadvantages of canvas pipe are rapid decay in stagnant, humid air, rapid disintegration from the dilute acids found in mine water, and inflammability.

An experiment in one Butte mine showed that ordinary cotton string lost about 30 per cent of its strength by exposure for less than 24 hours to the stagnant, humid air at about 70° F. Several manufacturers are experimenting on a treatment of canvas tubing that will retard decay, enable it to resist weak acid waters, and make it noninflammable. Development of a reasonably cheap process will aid greatly in the ventilation of blind ends in metal mines.

Experiments at Butte indicate that the coefficient of friction of canvas pipe is less than that of galvanized iron pipe of the same size; in addition, canvas pipe can be placed much more easily and cheaply. It turns corners of almost 90° without elbows; it is more easily kept tight at the joints than metal pipe, and can be held closer to the face. Its many advantages make it popular in Butte, and its use has facilitated greatly the ventilation of many places that were hot, humid, and unhealthful. Views of canvas pipe as installed are shown in Plates II, *B*, and III, *A* and *B*.

SUMMARY.

QUANTITY OF AIR SUPPLIED.

At least 75 per cent of the Butte mines have mechanical ventilation and nearly all of these mines have enough air for the number of men employed. A few of the mines that use natural ventilation and have at least one upcast and one downcast shaft to the lower levels of the mine have also an adequate supply for the number of

men employed, at least at certain seasons of the year; but some of the mines that use natural ventilation and have at least one upcast and one downcast shaft have an inadequate quantity of air in circulation, especially in extensive workings. Mines that have only one shaft and no air connections to other mines almost invariably lack an adequate supply and circulation of air, even mines that are shallow—that is, less than 1,000 feet deep—and probably even when equipped with a fan.

QUALITY AND DISTRIBUTION OF AIR.

Most of the Butte mines have enough air flowing through them to meet the requirements of the men employed, and analyses of samples from the main returns show little vitiation, yet proper distribution of the air to the places where it is most needed is lacking in all the mines. Even in those mines having the best circulation of air, fewer than 50 per cent of the working faces have an air movement that can be detected even by close observation of the deflection of a candle flame, and fewer than 30 per cent of the raises and stopes have an air movement that can be detected with a candle. Blind ends constitute most of the working faces or breasts, and in probably 25 per cent of the blind ends of drifts, crosscuts, raises, and stopes the circulation of air is entirely inadequate; air depleted of oxygen or containing excessive CO_2 , or containing explosive fumes, hangs so much that the men work with almost continual headache; in the poorly ventilated mines the percentage of such places may approach 90 or even 100, the only relief coming from compressed-air blowers and in the issuing air within a few feet of the end of the hose.

TEMPERATURE AND HUMIDITY OF AIR.

High temperatures, both wet and dry bulb, high humidity and the vitiation of air by decrease of oxygen, increase of CO_2 and fumes from explosives all have a decided influence on the healthfulness or the comfortableness of an underground working place; the main determining factor in the mines, as elsewhere, is the volume of air moving, or if temperatures are high the velocity of the air.⁴ In pure, still air, comparatively little discomfort is felt until the temperature rises above 75°F. , even with a relative humidity of practically 100 per cent; at temperatures below 75°F. , a depletion of oxygen, amounting to 1 per cent or over, or the increase of the CO_2 content to 0.30 per cent or over, or a small amount of fumes from explosives with

⁴ Crowder, T. E. The ventilation of sleeping cars: Comparative tests of various types of exhaust ventilators. (A discussion of principles of ventilation) Trans. Heating and Ventilating Eng., vol. 21, 1915, pp. 135-210, p. 560.

0.05 per cent or more of CO, quickly manifest themselves in headache, shortness of breath, and other signs of distress. In air like that described above, however, excepting the CO content, moving at more than 100 linear feet per minute, no appreciable discomfort is noticeable until the depletion of oxygen is about 3 per cent; men seemingly work to fair advantage in the moving air even when a candle or match does not remain ignited, though a carbide lamp burns brightly.

High oxygen depletion of cool, moving air was not found in the Butte district. When the wet-bulb temperature was between 75° and 80° F. and there was no circulation of air, discomfort was usually felt even when the relative humidity was low and was especially noticeable if the air was slightly vitiated. The manifestations were excessive perspiration, possibly headache, and slight dizziness, and nausea. With a velocity of 100 linear feet per minute or more, however, such air, between 75 and 80° F, causes little or no discomfort, even though of high humidity. In fact, several places in which the air temperature was 80° F. and the humidity was 98 to 100 per cent, but the air current was swift, were distinctly pleasant.

In still air, with the temperature between 80° and 90° F., a feeling of oppression was felt, especially when the relative humidity was above 95 per cent, or when even a small amount of fumes from explosives were present, or when there was a slight depletion of oxygen or an increase of CO₂. Upon coming into a still atmosphere with a temperature of 80° to 90° F. and a high relative humidity, the investigators frequently took samples of air in the expectation of finding heavy depletion of oxygen, but analyses repeatedly showed a depletion less than one-half per cent and a CO₂ content less than one-fourth per cent, indicating the effect on the human system, under such conditions, of small changes in the chemical content of air. Headache is likely to be experienced quickly, probably accompanied by slight dizziness and occasionally by nausea. Manual labor causes the bodily temperature quickly to rise above 100° F. and frequently to 102° or 103° F., while the blood pressure falls rapidly.³ When such air had a velocity of 400 or 500 feet or more per minute, its effect on the human system was pleasant rather than otherwise, even though relative humidity was close to 100 per cent, or the oxygen content as low as 19.5 per cent, or the CO₂ as high as one-fourth per cent.

In still pure air with wet-bulb temperatures of 90° to 95° F., and with low relative humidity, much discomfort is felt, though such air is endurable if moving at a rate of 500 feet per minute or over, mark-

³ Sayers, R. R., and Harrington, D., A study of the physiological effects of high temperatures and high humidities in metal mines. U. S. Public Health Service Report 639, 1921, 16 pp.

edly so when relative humidity is low; in still air at 90° to 95° F. even slight oxygen depletion, excess of CO₂, or fumes of explosives are quickly noticeable, and headache, faintness, dizziness, nausea, and mental dullness are likely to follow the breathing of such air for any considerable length of time, in as short a period as one hour.

The writer has stood in a swiftly moving current of air having a temperature of 95° and a relative humidity over 95 per cent without feeling especially uncomfortable; it is probable that little discomfort would be occasioned by a temperature of 95° and relative humidity as high as 98 per cent, provided the air had as high a velocity as that issuing from a fan-and-canvas-pipe ventilation system.

FACTORS INFLUENCING TEMPERATURES OF MINE AIR.

Agencies affecting the temperatures of the air in Butte mines were of importance in about the following order: Underground rock and water temperatures; surface air temperatures; oxidation of timber and sulphide ores; mine fires; volume of air circulating; friction of air flow due to velocity; movement of ground; firing of shots; miners' lights, and breathing of men and animals; and heat from electric motors.

TEMPERATURES OF ROCK AND WATER.

Normal rock temperatures in areas unaffected by fires and rock movement increased about 1° F. per 100 feet of depth, being 100° F. at about the 3,200-foot level. Air flowing at the approximate rate of 400 linear feet per minute increased or decreased in temperature at the approximate rate of 1° per 100 feet of travel, until air and rock temperatures approached equality; in those parts of a mine where there was little or no air in circulation, the air almost always had practically the same temperature as the surrounding rock except in places where there were water drippers. The drippers had greater influence than the rock temperature in determining the temperature of the surrounding air.

Continuous flow of a stream of air may increase or decrease the temperature of the surrounding rock walls; in one place a continuous flow for four years of about 20,000 cubic feet of air per minute at a velocity of about 500 feet per minute, reduced the original rock temperature from 98 to 68½° F.; on the other hand, a continuous flow for two years of about 20,000 cubic feet of air at 81½° F. raised the original rock temperature from 72½° to 78° F.

TEMPERATURE OF SURFACE AIR.

Surface temperatures vitally affect the circulation of air in most mines using natural ventilation; in mines less than 1,000 feet in

depth the rock temperatures are likely to be less than 65° , especially when modified by water from the surface; when the temperature of the surface air becomes essentially that of the rock underground, there is likely to be practically no circulation. Table 1 indicates that in Butte maximum daily surface temperatures in 1916, 1917, and 1918 ranged from 44° F. in the winter to 94° F. in the summer, the average range between minimum and maximum being over 55° ; hence at shallow mines there were days in every month of the year, except in December, January, and February, when the temperature of air outside equalled that of the rock inside, and the movement of air underground was slight. In shallow mines relying on natural ventilation days of slight air movement are commonest in spring and fall, unless a mine has cool, falling water in its downcast shaft, and in the deeper mines such days are most numerous in summer.

On the other hand, surface temperatures have comparatively little effect on the deep mines with mechanical ventilation, as temperatures in the main downcasts, except for a summer-winter variation of 5° to 10° , are practically constant below the 2,000-foot level irrespective of the hour-to-hour or the day-to-day variations of outside temperatures; excepting, however, when the temperatures outside exceed the usual constant temperatures at the various stations below 2,000 feet in the downcast shaft, the temperature of the underground air leaving these stations is higher than the normal for the summer, but it quickly returns to the normal when the temperature of the outside air falls at evening.

OXIDATION OF TIMBER AND OF SULPHIDE ORES.

In many places slow moving air leaving abandoned timbered areas, where no fires had ever existed, was warmer than the air that entered the area, and warmer than the rock temperature, the increase ranging from 1° to as much as 30° . The probable cause of this warming is the oxidation of timber or of sulphide ore, or of both. Moreover, analyses of the heated air from such areas almost invariably showed a depletion of oxygen and an excess of CO_2 , indicating chemical reactions with probable release of heat, the rise of CO_2 and the deficiency of oxygen being far in excess of amounts attributable to other sources. Oxidation of timber and ore are probably responsible for an increase of several degrees in temperature of the air in Butte mines.

MINE FIRES.

In several of the larger Butte mines are fires of long standing, which greatly handicap ventilation and other operations in these mines and frequently in adjoining mines. Exactly how much the temperature of the air circulating in these mines is affected by the

fire is not known, except for one mine in which the increase was determined definitely to be at least 5.8° F. in all working places in one vein, these places not being in the fire region. It is entirely probable that through interruptions of ventilation and the heating of rock adjacent to air courses some of the mines have their average air temperature increased 5° F. by mine fires. It is possible that an increase of 10° F. would be more nearly correct.

VOLUME OF AIR IN CIRCULATION.

The quantity of air in circulation determines the velocity. In Butte mines the increase of temperature in currents having a velocity of even 400 feet per minute amounted to about 1° per 100 feet of travel. Most drifts have a cross-sectional area of 35 to 40 square feet, and with a velocity of 400 linear feet per minute the volume required to keep the temperature increase at 1° per 100 feet of travel would be 14,000 to 16,000 cubic feet per minute. As 2,000 feet of travel would increase the air temperature about 20° or more, and air leaving the downcast shaft below the 2,000 level is rarely cooler than 60° , it is almost necessary, if the working temperature is held to less than 80° F., to limit the travel to 2,000 feet or less. Hence each air split should not have to travel more than 2,000 feet between the downcast shaft and the last working place ventilated. This requirement would mean, in general, that air in Butte mines should not traverse more than two levels, and preferably only one, before being returned to the upcast shaft. If there were 10 working levels, at least 70,000 cubic feet of air per minute, divided into 10 splits, would be necessary. Splitting the air is absolutely essential. Those few mines that in part have adopted splitting have been surprised at the consequent reduction of temperature.

FRICTION OF AIR FLOW DUE TO VELOCITY.

In most mine workings at Butte the increase of air through friction, caused by velocity of flow, is probably not great and to measure it separately from the increase due to rock or water temperature, oxidation, or fires is difficult. Increases of air temperature through friction during travel at high velocities through galvanized pipe or canvas tubing can be readily measured and is of considerable importance. This increase in air temperature is dependent on many factors, such as the size and type of fan with special regard to friction, and the length, diameter, and kind of tubing, the velocity of the air, the number of elbows, and the condition of the tubing, whether wet or dry. For ordinary use in mine ventilation, however, certain data were obtained for velocities of 3,000 to 6,000 feet per minute through 8, 10, and 16 inch tubing in lengths of 500 feet or less.

In 500 feet of dry 10-inch canvas tubing, air traveling at a velocity of 4,800 linear feet per minute had its temperature increased 2.17° F. per 100 feet traveled; in 400 feet of dry 8-inch canvas tubing, air having a velocity of 3,500 linear feet per minute had its temperature increased 3.62° F. per 100 feet of travel; and in 300 feet of dry 16-inch canvas tubing, the velocity being over 4,000 linear feet per minute, the increase was 2.17° F. per 100 feet of travel. Though there were many bends of 5° to 20° in the tubing, there was but one 45° elbow, this being at the fan.

When sprays of cool water were introduced into the fan intake or cool drippers kept the canvas tubing saturated, there was little or no increase of temperature during flow through the tubing. Placing galvanized-iron elbows 45° or 90° in either the canvas or the galvanized-iron tubing greatly augmented the increase of temperature per 100 feet of travel. The increase of temperature in travel through galvanized-iron tubing was essentially double that through dry canvas tubing, the sizes of tubing, the velocities, and other factors being similar.

Although air became warmer by traveling through tubing, yet its relative humidity decreased. The high velocity and the comparatively large volume of the discharge make this system of auxiliary ventilation very effective.

GROUND MOVEMENTS.

Ground movement is responsible for considerable increases of air temperature in some places and is probably of general importance, inasmuch as 3,000,000,000 cubic feet or more of material has been extracted at various depths under the 4,000 acres comprising the chief mining claims of the district, the total bulk of the excavation equaling 18 feet for the entire area. That settlement has taken place is proved by levels of the United States Geologic Survey which show that the area around the Butte post office sank from 10 to 11 inches in two years. Moreover, as the veins dip about 70° and lie parallel at intervals of a few hundred feet there must be movement when veins are mined. Shafts and other underground workings give forcible and costly intimations of such movement, the progress of which undoubtedly generates much heat.

SHOT FIRING.

Firing the shots that require about 7,000,000 pounds of 30 to 40 per cent dynamite annually increases air temperatures several degrees in confined, ill-ventilated blind ends, but has comparatively little effect in the aggregate.

HEAT FROM LIGHTS, BREATHING OF ANIMALS, AND ELECTRIC MOTORS.

Heat from miners' lights and the breathing of men and animals has considerable local effect on temperature, especially at poorly ventilated faces of raises, drifts, crosscuts, and stopes in narrow veins, but has little appreciable effect on the temperature of the air of the entire mine. Heat from a large motor in a confined place may cause an increase of 5° F. or more in the station or its surroundings, but has little or no appreciable effect on the general underground temperature.

FACTORS INFLUENCING HUMIDITY OF MINE AIR.

The factors found by the investigators to affect the humidity of mine air are given here in the order of their relative importance: Invisible moisture in downcast shafts and other workings; visible moisture and water in underground workings; humidity of outside air; fans and galvanized-iron or canvas tubing.

INVISIBLE MOISTURE IN DOWNCAST SHAFTS AND OTHER WORKINGS.

Even in downcast air currents moving 700 linear feet per minute, though said to be dry—that is, with no visible water from sides—the relative humidity of dry surface air increased as much as 1.2 per cent per 100 feet of travel downward until it reached about 70 per cent or over. Very little air left the downcast shafts below the 2,000-foot level at less than 70 per cent relative humidity, even when the relative humidity of the surface air was 30 per cent or less. On the other hand, when the relative humidity at the surface was high, generally with temperatures below 50° F., the rise of temperature of the descending air was so rapid that the relative humidity fell, again reaching about 70 per cent at the 2,000-foot level; in other words, the relative humidity at the shaft stations below the 2,000-foot level was practically a constant, irrespective of the relative humidity at the surface, and practically no downcast air entered the mine below the 2,000 with less than 70 per cent relative humidity.

In comparatively dry drifts or crosscuts below the 2,000 level, where rock temperatures are high, and the air velocity about 400 linear feet per minute, the increase of relative humidity was about 0.22 per cent per 100 feet of travel, or somewhat less than in the downcast shaft mentioned; in some drifts or crosscuts with wet sides or back or with roof drippers the increase of relative humidity was 5 per cent or more per 100 feet of travel, even in air with high velocity. In slowly moving or stagnant air, as in most blind ends, the increase of humidity was very rapid; in slow-moving air the relative humidity increased 5 to 10 per cent per 100 feet of travel until

it reached 85 to 90 per cent; and at very few of the deeper working places was the relative humidity less than 85 per cent in still air.

VISIBLE MOISTURE AND WATER IN UNDERGROUND WORKINGS.

Water flowing on the floor or standing in a pool on the floor tends to increase the relative humidity of surrounding air, yet its influence is by no means as great nor is its action nearly as rapid as that of water falling in drippers and spray. In a downcast shaft where there was a copious flow of water at 48° F., the entire intake current of the mine reached the 800 and 1,200 stations practically saturated with moisture, irrespective of the humidity of the surface air. In drifts air issuing from the end of canvas pipe at a velocity of several thousand feet per minute and flowing through less than 25 feet of drippers increased in relative humidity from 71 to 97 per cent, but part of the increase was due to the rapidly moving stream of air from the end of the canvas pipe drawing with it the surrounding air which had a relative humidity of about 90 per cent.

HUMIDITY OF OUTSIDE AIR.

Day-to-day or hour-to-hour changes of relative humidity at the surface have little influence on the relative humidity of air below the 2,000-level in downcast shafts at Butte, even when the velocity is high; there is, however, a seasonal variation of relative humidity at shaft stations, the relative humidity in winter averaging about 10 per cent lower than in summer.

In shallow mines, 1,000 feet or less in depth, with workings close to a shaft and with fair velocity, surface temperature and humidity have direct and far-reaching influence on the temperature and humidity of mine air, whether the mines rely on natural or on mechanical ventilation. Even in such mines, however, though workings close to the shaft may have air approximating surface air, the temperature may change rapidly, the latter soon nearing saturation and the former quickly approaching rock temperature.

USE OF SMALL FANS AND CANVAS OR SHEET-IRON TUBING.

When air is forced rapidly through galvanized iron or dry canvas pipe, its temperature usually rises rapidly with corresponding drop in relative humidity. In spite of the air becoming warmer, its velocity and lower relative humidity make this method of ventilation highly successful in relieving depressing conditions in blind ends. The decrease in relative humidity in air flowing through canvas tubing at high velocities was as much as 5 per cent per 100 feet of travel; in a length of less than 100 feet of galvanized-iron tubing the

decrease in relative humidity was at the rate of over 31 per cent per 100 feet of travel.

FACTORS INFLUENCING COMPOSITION OF MINE AIR.

In general, the chemical composition of the air in Butte mines was satisfactory, the main return air at the surface generally but not always comparing well with that of outgoing air in the best coal-mine practice, except that the depletion of oxygen was somewhat higher than in coal mines. At many poorly ventilated faces of cross-cuts, drifts, stopes, and raises, however, the air was rather badly depleted of oxygen or carried excessive quantities of CO_2 , CO, or other gases.

Factors that affect the composition of underground air stood about as follows in relative importance: Oxidation of timber and ore; fumes from explosives; gases from mine fires; miners' lights, and breathing of men and animals; composition of compressed air; composition of outside air.

OXIDATION OF TIMBER AND ORE.

In still or slow-moving air in timbered places there was heavy depletion of oxygen, with an increase of CO_2 , but the CO_2 increase was not in proportion to the loss of oxygen; the average depletion of oxygen in 18 samples of so-called timber gas was 1.03 per cent, and the average content of CO_2 was 0.44 per cent, the amount of CO_2 necessary to absorb the entire loss of oxygen being 1.41 per cent, instead of the 0.44 per cent found. Hence the timber probably absorbed about 70 per cent of the oxygen, and with the other 30 per cent formed the CO_2 given off.

This oxidation of timber seemingly takes place at any temperature above 60° and progresses fastest when a white fungus is present. This fungus was found in greatest luxuriance where the relative humidity was 95 to 100 per cent. Where there was air in a timbered place with high relative humidity and little or no movement for a few months, the depletion of oxygen was practically complete. On the other hand the most rapid decay of timber was in main returns, with velocities of 500 to 1,000 feet per minute, temperatures above 70° F. , and a relative humidity of 100 per cent. On several occasions air currents of 5,000 cubic feet per minute coming from idle or abandoned workings were found to be much depleted of oxygen and to carry 0.50 per cent or more of CO_2 .

FUMES FROM EXPLOSIVES.

Inasmuch as explosives are used at nearly all working faces, many of which are poorly ventilated, fumes from explosives, though not

of much importance in their effect on main air currents, exercise a vital influence on the health and comfort of men working in blind ends. Detailed examination showed that over 50 per cent of such places in Butte mines had no discernible movement of air, and about 20 per cent of the other places the air had only the slightest movement. CO gas was found in proportions of about 1 per cent after firing a round of holes with 40 per cent gelatine; to breathe air thus contaminated would be fatal in a few minutes. A CO content of about 0.1 per cent was often found. Even where the air revealed no harmful constituents by analysis, men were often found complaining bitterly of headache from "powder gas."

GASES FROM MINE FIRES.

In mines that have long-standing fires, or in mines adjoining them, noxious gases frequently get into general ventilating currents, or enter stopes through cracks in the vein or country rock. Besides causing occasional mysterious deaths, these gases cause also much temporary illness, nausea, and headaches. Mine fires cause depletion of oxygen; a heavy increase of CO₂, up to 20 per cent or over; various percentages and often a deadly amount of CO proportions of methane (CH₄), the inflammable gas of coal mines, that exceed the explosive limit of 5 per cent; irrespirable amounts, more than 0.1 per cent of SO₂; small quantities of H₂; and also arsenical gases, and possibly others.

It was possible in this investigation to explode the metal-miner's fallacy that any place in which a candle or carbide light will burn is safe. In at least one instance a miner was killed by CO gas from a fire in an adjoining mine, but when his body was removed his carbide light was burning brightly. The gas, locally known as "sweet gas," was shown to contain CO, frequently in dangerous amounts.

In general, the gases from mine fires were confined or were isolated from the ventilating currents, but at many places considerable volumes of fire fumes leaked into the general current. Upon the occasion of an unexpected new fire, or the outbreak of an old fire, dangerous fumes from a fire in one mine were conducted to adjoining mines because of the numerous break-throughs and the inter-ventilation of the mines.

MINERS' LIGHTS AND THE BREATHING OF ANIMALS.

In many confined, ill-ventilated places there was considerable air vitiation that could be charged only to miner's lights and the breathing of men and animals, as the timber was new and the places were advancing daily. This depletion of air in confined places was so great at times that a candle would not burn until the full stream

of compressed air had been used for some time. The proportion of such places, however, was not large.

COMPOSITION OF COMPRESSED AIR.

Many complaints were made by miners that the compressed air was impure and caused illness, yet numerous analyses of compressed air failed to show any undue depletion of oxygen, and none revealed the presence of any gas that should cause illness.

COMPOSITION OF OUTSIDE AIR.

In general, the outside air was pure during the investigation, though in winter many days were cloudy or foggy, there being an average of 238½ cloudy or partly cloudy days each year in 1916, 1917, and 1918. The analysis of outside air on one of the worst of these days revealed the presence of a perceptible amount of SO_2 gas and a slight increase of CO_2 . As Butte mine shafts are so close to each other, it is probable also that some impure air from upcast shafts—air carrying about 0.30 per cent CO_2 , with possibly some CO from mines with fires, and having an oxygen depletion of about 0.75 per cent—is taken into the downcast shafts.

CHIEF REASON FOR POOR DISTRIBUTION OF AIR UNDERGROUND.

The main factor contributing to poor distribution of air to the working faces in Butte mines is a lack of knowledge by the mining engineers, foremen, shift bosses, and miners of the principles of mine ventilation, including the effects of heat, humidity, and mine gases on the human system and on the flow and distribution of air; and also, lack of experience in the use of doors, regulators, stoppings, and brattice for directing air currents. Not only is there a lack of knowledge, but there is also a well-defined attitude, especially among old-time mining men, whether mining engineers or practical miners, that to circulate air at the working faces is necessary only in coal mines.

In addition, the fact that many Butte mines, under the present system of ventilation, must obtain air from or through other mines, or must discharge air through other mines, causes much dangerous friction and inefficiency. A foreman of one mine went to the expense of reopening and retimbering a crosscut for purposes of ventilation, only to find that later the extension of the air course in an adjoining mine was used for storing timbers, pipe, etc., and that practically no air could flow through it. As another example, a mine that had only one shaft below the 2,000 level but had two connections to adjoining mines was deprived of necessary ventilation be-

cause the owners of the adjoining mines refused to allow air to pass through those openings.

FINANCIAL ASPECTS OF EFFECTIVE VENTILATION.

Continuance of unfavorable working conditions underground results in impaired health for mine workers and in immense financial loss to operators. In a section of a mine having unusually poor ventilation and high temperature and humidity, a bonus of 25 cents a day over the regular wage was paid, the working shift was reduced from 8 to 7 hours, and while one man worked his partner sat under a compressed air hose to cool and to recuperate. The maximum efficiency of the worker, who had to be a man of exceptional endurance, was much less than 50 per cent, probably not over 30 per cent, yet he received a bonus of $12\frac{1}{2}$ per cent in reduced length of shift, and an increase of 25 cents per shift in pay.

In another mine, in a place on a much deeper level, with rock and water temperature exactly 10° higher than in the place described above, a stream of air was forced to the face by a fan through 400 feet of canvas pipe. Three contract workers, in a moving current with temperature 85° F., relative humidity 90 per cent, drove a 5 by $7\frac{1}{2}$ foot crosscut in solid granite an average of $4\frac{1}{2}$ feet per shift, at \$5 per foot, netting each \$7.50 per shift. They worked continuously, but suffered no evident ill effects. To obtain men to drive a crosscut about 2,000 feet from circulating air, with compressed air for ventilation, and with rock and water temperatures slightly under 80° F., proved almost impossible. Installing a fan and canvas pipe that delivered to the face about 4,500 cubic feet of air per minute at $79\frac{1}{2}^{\circ}$ F. and 100 per cent relative humidity, made it easy to obtain and hold men and cut the cost of driving over 40 per cent.

In another mine a drift was being driven through rock having a temperature of 98° F. at a contract price of \$5.50 per foot, and practically no progress was being made. After the installation of a No. $2\frac{1}{2}$ fan, driven by a $7\frac{1}{2}$ -horsepower motor, and 400 feet of 10-inch canvas pipe to deliver somewhat less than 2,000 cubic feet of air per minute to the face, the contract rate was reduced to \$4.50 per foot and the men worked steadily, making about $3\frac{1}{2}$ feet daily. Here the saving of \$1 per foot amounted to \$70 per month if the men worked 20 days and drove $3\frac{1}{2}$ feet per day; from this amount should be deducted the power cost, $7\frac{1}{2}$ horsepower, at \$2.50 per horsepower per month, or \$18.75, and the depreciation and repairs on the fan and the canvas pipe, 30 per cent per month on the canvas pipe, and $2\frac{1}{2}$ per cent per month on the fan and the motor, amounting to about \$32.50 per month, a total deduction of \$51.25 per month, leaving the net gain to the company \$18.75 per month. In addition the improve-

ment paid for the entire cost of the canvas pipe in $3\frac{1}{2}$ months; the entire first cost of the fan and electric motor in $3\frac{1}{2}$ years; and provided a comfortable, healthful place for the workers where they could work steadily and earn nearly \$8 each per shift.

In sinking a Butte shaft 50 feet of progress was made one month and 60 feet the next month, the rock temperature being 100° F. or over. After the installation of a fan and the canvas pipe the shaft was sunk 130 feet the first month.

Many similar instances can be given but those above are typical of what can be done with a fan and the canvas pipe. Hundreds of instances can be given in which a slight amount of work and the use of coal-mining methods of deflecting air would save money for the company and provide much better working conditions for the men. Four men, working in hot, stagnant, humid air, at the face of a crosscut, said they were able to remain at work only one-third of the time, the remaining two-thirds being spent cooling off in a drift only 120 feet distant where there was a strong current of air, with a temperature 15° lower than that at the face. Here was a daily loss to the company of two-thirds of each of the four workers' daily wage of \$4.75 or a loss of \$12.67 per shift, two shifts being employed, because no one threw up a brattice to lead the entire current to the face, as could have been done in less than one shift by one man in a coal mine. A man, who had been a coal miner, working in a typical Butte stope, obtained a piece of canvas that he placed across the drift below, forcing the air up into his stope and giving him a reasonably comfortable working place. A fellow workman, running an electric motor on the drift, tore the canvas down, and refused to have it put back, threatening a strike if the motormen were compelled to pass through canvas brattices across drifts.

In Butte mines a good day's work for a mucker is loading 15 cars⁴ of ore or waste, yet in cool, well-ventilated places contract men readily load 45 to 60 cars. Many foremen and shift bosses, as well as other officials, said that their men worked not more than 50 per cent of the shift, admitting frankly that conditions in many places made it physically impossible for men to work steadily or efficiently. The shirkers thus have an opportunity to establish a standard for the camp; men working under really good conditions refuse to deliver more work than those in the poor places, which constitute a majority of all the places. It will be useless to attempt to raise the present admittedly low standard of efficiency among underground workers in Butte until working conditions in most of the working places are decidedly good.

⁴ Capacity, 1,400 pounds each.

A 30 per cent loss of efficiency, due to defective mine ventilation, among men working underground at Butte, is probably a conservative estimate, but, figured for each of the 13,000 underground workers in 1917 and 1918, with a wage of \$5.75 per shift, this loss amounts daily to \$22,425, totaling in 300 working days per year \$672,750.

Another serious loss to the Butte companies is the extremely high labor turnover, due partly to general economic condition but mostly to unfavorable working conditions underground. In 1916, 1917, and 1918 this turnover averaged over 500 per cent per year, frequently running well over 100 per cent per month. With about 13,000 underground employees about 65,000 men have to be hired annually to keep up the working force. Butte mining men estimate a cost of \$10 to \$25 every time a man leaves and is replaced; if the lower limit of \$10 is taken, the total annual loss would be \$650,000, a large proportion of which is due to unfavorable working conditions underground.

The excessive use of compressed air by workers in poorly ventilated places in an attempt to secure relief constitutes a heavy economic loss. In most of the mines investigated workers were utilizing compressed air in over half the places visited, and it was estimated that in some mines the compressed-air blowers consumed at least 5,000 cubic feet of air per minute. It is a conservative estimate that in the 30 or more large mines of Butte at least 50,000 cubic feet of compressed air per minute was used for blowers, all of which could be eliminated by efficient ventilation. The cost per month in compressing 50,000 cubic feet of air per minute during two 8-hour shifts daily runs well over \$30,000. A far greater financial loss, however, is sustained in the decreased efficiency of compressed-air drilling machines through using air at 30 to 40 pounds pressure per square inch. If the drills were the only consumers of compressed air the working pressure would be 60 to 80 pounds.

The economic loss to the 13,000 workers from unfavorable working conditions is difficult to estimate, but undoubtedly it is important, arising from lost time due to pneumonia, miners' consumption, and such diseases prevalent among Butte miners, which are caused in large measure by unfavorable and unhealthful underground working conditions. It is known that at least 150 Butte miners die annually from miners' consumption. After examining over 1,300 Butte miners in 1917 and 1918, Dr. A. J. Lanza, of the United States Public Health Service, estimated that at least 20 per cent of the underground workers who had been employed five years or more in Butte mines had miners' consumption. He decided that the primary cause of the prevalence of the disease was inhaling the dry, finely divided siliceous dust, and the secondary cause was working in stagnant, hot, humid, and vitiated air.

The cost of providing adequate ventilation in the mines of Butte can be only roughly estimated. Coal mines are ventilated generally at a cost less than 2 cents per ton of coal produced; on that basis to ventilate the mines of Butte, which produced approximately 6,000,000 tons of ore in 1917 and 1918, would cost \$120,000 annually. For a few years at least, however, the cost might run as high as 5 cents per ton, as so little has been done in the past toward providing air currents at working faces; this rate would involve about \$300,000 annually, based on the 1917 and 1918 tonnages. Approximately 4,000 horsepower probably would be needed to drive the necessary fans and blowers, at a power cost of \$2.50 per horsepower per month, or \$120,000 per year; in each of the 30 representative mines there should be at least one man whose entire attention should be devoted to ventilation; their salaries would amount to about \$75,000 per year. Repairs, interest, and depreciation on electrical installations would amount to about \$100,000 per year.

RECOMMENDATIONS.

Some of the Butte mining companies have begun an intensive study of ventilation, and have made considerable progress, but others have done very little toward improving admittedly bad conditions. The following recommendations cover measures proposed to improve conditions as they existed in 1916, 1917, and the first half of 1918. Some of the recommendations, at least in part, have been carried into effect already by some mines or companies.

1. Each mining company in Butte that employs 100 men or over underground should have a man in charge of ventilation. Preferably this man should have a technical education and have had experience in mine ventilation elsewhere, either in coal or metal mines, in addition to practical metal-mine experience. He should have full charge of ventilation apparatus and personnel on the surface and underground, reporting only to such higher officials as the general superintendent or the general manager. This man should make a detailed underground study of the mine or mines under his direction, measuring, locating, and mapping the air currents and temperatures. He should then formulate a general plan of ventilation and should have authority to carry it into effect.

Each large mine should have at least one man whose sole duty should be to take care of ventilation apparatus, doors, and regulators, as well as to make extensions in order to maintain the ventilation of working faces. This person should report to and be under the instruction of the ventilation superintendent only; where two or more mines are so connected and equipped that they require air currents

from one mine to ventilate the other, the ventilation work and apparatus should be under the direction of one man whose regulations should have authority over the mine foreman and all other underground employees.

2. Every Butte mine that connects with adjoining mines should enter into mutual agreements pertaining to the exchange of air, to doors in the openings connecting mines, and similar matters. The making of such agreements is of vital importance, and in the opinion of the writer should be handled by some State official, preferably the State mine inspector, who should have authority to compel joint action in the interest of the health and safety of the men working in the mines affected.

3. All Butte mines should have mechanical equipment for ventilation, preferably a fan on the surface, readily reversible or so arranged that air currents may be reversed quickly. The fan house should be fireproof. Main fans should be kept in continuous operation, even during the shift or shifts when men are not working.

4. Each operating mine should have its own upcast and its own downcast shaft to the lowest stoping level. If possible, all air shafts should be smooth lined with fireproof slabs, gunite, or other fireproof material. Mines with only one shaft should have the shaft separated into at least two compartments by an air-tight, fireproof partition, and the downcast compartment at least should be gunited or otherwise fireproofed. Falling water tends to cause the air to flow down a shaft, thus retarding the flow in upcasts. For this reason it should be caught at intervals in an upcast shaft and conducted away from the shaft. Where possible the air shafts should be separate from the hoisting shafts. In air shafts having compartments for hoisting and others without hoisting equipment, smooth lining the latter would greatly increase their capacity.

5. Close to all air shafts, both upcast and downcast, there should be fireproof doors in fireproof frames, so placed at each level along the shaft that by closing doors the shaft can be completely isolated from the rest of the mine. The doors should have some device such as a latch or pulley and weights whereby they can be held closed, irrespective of the direction or pressure of air currents. This device is of vital importance at time of fires in shafts or shaft stations. If possible, the doors should be so constructed that they may be closed from the surface by some electrical or mechanical device. Direct passage of air between the upcast and downcast shafts should not be permitted unless necessary, as it might cause both shafts to be cut off by fumes from a fire in the downcast shaft or at station in that shaft. Doors with a latch or pulleys and weights should be placed in all levels connecting upcast and downcast shafts, and where possible these doors

should be kept closed all the time. Open levels between upcast and downcast shafts are dangerous in the event of a mine fire.

6. Definite, systematic splitting of air currents is vital to safe and efficient distribution of air. Each main split should contain 10,000 to 20,000 cubic feet of air per minute, and this quantity should be held together as much as possible and deflected to working faces by the use of proper doors, stopings, bulkheads, brattices, and regulators, where possible. Air should be conducted from the intake shaft into the mine through the drifts, crosscuts, and stopes of one level and directly to the upcast through the drifts, crosscuts, and stopes of the level immediately above, thus limiting the amount of time the air remains in a mine and the amount of ground traversed; and giving ascensional ventilation. Doors should be so placed that the entire split may be closed off when desired.

7. In order to concentrate air currents and to conserve them for use in active workings, all abandoned drifts, crosscuts, manways, and stopes should be closed by air-tight bulkheads, brattices, and doors. Suitable signs should be posted to warn all persons against entering such closed or abandoned places. This arrangement would serve to reduce the oxidation of timbers in abandoned places thus lessening the present vitiation of underground air, and by holding air currents concentrated it would permit their reaching active stopes, manways, drifts, and crosscuts by use of fireproof curtains, brattices, and doors, as in coal mines.

8. For ventilating blind ends at considerable distances from circulating air, the use of small electrically driven fans and canvas or galvanized pipe is commended. The air issuing from a pipe at a face not only removes explosives fumes, and dust but it enables the men to work in a current of air which is probably the most essential feature in the improvement of present conditions of ventilation. All underground fan stations, whether permanent or temporary, should be of fireproof construction; and fan motors should have fireproof setting. A more general use of booster fans is advised to increase air movement underground.

9. In the Butte district it is not possible to plan a ventilating system before beginning operations, as is done in coal mining, yet it seems feasible to make certain modifications in present practice in order to facilitate the flow of air. Some of the modifications suggested are as follows:

(a) As soon as stoping has begun in a new mine a raise should be driven to the surface to give circulation of air.

(b) In some mines the custom has been established of driving a parallel lateral in the footwall about 50 feet from the drift in the vein several months after the driving of the drift. It is recom-

mended that a lateral be driven at the same time as the drift with connecting crosscuts every 50 or 100 feet. This method, aided by a little bratticing and the closing of all the connecting crosscuts but the last one near the face, would insure well-ventilated working faces in both drift and lateral.

(c) Raises and chutes in Butte mines are in general 25 to 50 feet apart; if they were driven in pairs with break-throughs every 40 or 50 feet, air movement in the raises would be greatly facilitated.

(d) In driving three-compartment raises, one compartment with timber slide, air and water pipe, and ladderway, the middle one for ore chute, and the third compartment without platforms or other obstructions for downcast air, it would not be difficult to ventilate the top of the raise, especially if a small spray of water were kept falling in the third or downcast compartment. The water spray would also aid in keeping the place cool and free of dust.

(e) In present mining systems at Butte, raises have two compartments. One compartment contains the ore chute, the other contains the ladderway with platforms every 30 feet, the timber chutes, and pipes, so there is little opportunity for air to flow. It is suggested that the platforms and other obstructions to the air flow should be removed from some of the manways which would then serve only as air courses. The open manways should be kept as near as possible to the working faces of stopes.

(f) The general adoption of the rill system, or of any system in which back filling is practically simultaneous with ore removal, and in which a comparatively small cross section of ground is open at any time, would permit a flow of air at sufficient velocity. In the ordinary system of overhead stoping with square-set timbering and subsequent back filling, several floors being open, it is not possible to introduce or concentrate air enough to give a velocity that will furnish relief to workers where the rock temperature is high. It is extremely desirable therefore to keep as few floors open as possible.

(g) In addition to closing off all abandoned places as heretofore recommended, the adoption of some means of closing tightly all openings to adjoining mines in case of fire is highly desirable. Abandoned stopes and drifts that have broken into adjoining mines should be sealed with air-tight bulkheads of concrete or of timbers laid skin to skin; places that must be maintained as escapeways but that have doors closed at ordinary times, should have the doors made air-tight with a thin concrete or gunite seal which can be broken readily; places that must be kept open to interchange air with adjoining mines should have two or three fireproof doors placed at intervals of 40 or 50 feet or less to provide an air lock, thus helping to prevent leakage of fire fumes when the doors are closed.

(h) The cross-sectional area of drifts and crosscuts in Butte mines is comparatively small. It seems feasible to increase the size of drifts and crosscuts, thus facilitating the flow of air, making provision for ground movement especially from the top or side, and increasing safety. In the present drifts there is little room between cars and timbers. Several men have been killed by coming in contact with trolley wires in raising the body above a car to pass timbers.

10. Nearly all Butte mines have available an abundant supply of pure, cool water, and it is strongly recommended that wider use be made of it to induce air movement, to cool the air in heated regions, and to allay the large quantities of dangerous, finely divided dust found in most working places.

In summer the use of a spray of the cool city water in downcast shafts would reduce effectively the temperature of the hot surface air to less than 70° F. before this air entered the mine workings. Throughout the year the use of a spray of cool water at intervals along drift and crosscut air courses would tend to neutralize the heating of the air in its passage along the rock walls, and would aid simultaneously in keeping fine siliceous dust from remaining in suspension in the air. Use of cool water at the faces of crosscuts, drifts, stopes, and raises would aid in cooling the surrounding walls and air, and in allaying dust and explosives fumes from muck piles. The dust menace alone demands that practically all working places in Butte mines should be piped with pure water. A water spray in one compartment of a three-compartment raise would induce the circulation of air, if the compartment were kept open and separated by tight partitions from the other compartments; the middle compartment, used for an ore chute, would be neutral as to the air flow; and the third compartment, used as a ladderway, would act as an upcast.

Advantage should be taken of drippers of cool water in shafts, drifts, and crosscuts in cooling underground air, with the knowledge that high humidity is of comparatively little detriment provided the temperature is held low and the air has sufficient movement. On the other hand, provision should be made to collect and conduct away from air currents or even from stagnant air drippers of high temperature, as they quickly cause the air to take their temperature. Comparatively large quantities of water in a pool on the floor or even in a running stream have much less effect in heating the air.

11. Mine doors form one of the most important features of safe and efficient underground ventilation. Doors should be substantially built, preferably of fireproof material. They should be hung so that they close flush against the outside of the frame rather than within the frame. If a door closes within the frame and the surrounding

ground moves, it will probably be impossible to open the door; on the other hand, though moving ground may warp the doorframe and prevent tight closing of a door hung flush with outside of the frame, a door so hung can always be moved.

Doors should be constructed so there is minimum opportunity for leakage of air under or around the door or through the frame. Where trolley locomotives are used, the opening for the trolley in the door or doorframe should be of minimum size; this requirement is especially important during mine fires. Where it is possible, doors should be placed in pairs, particularly on haulage roads, thus allowing one door to be closed while the other is open.

It is of utmost importance that doors should be so equipped that they are held closed positively by latch, by weights and pulleys, or otherwise; they should not be dependent upon the pressure of air. At the time of a mine fire, air currents are frequently reversed, causing the opening of doors supposed to be held closed by air pressure. Considerable loss of life in mine fires is traceable to doors thus hung. Doors should be equipped to close, not to open, automatically, as in times of emergency panic-stricken men can not be trusted to close a door equipped to open automatically.

12. Some miscellaneous suggestions for the improvement of the ventilation of Butte mines follow:

(a) If one mine must be ventilated or partly ventilated through another, both mines should be compelled to keep the necessary air courses free of obstruction and in good condition for the circulation of air. It has happened often, even in mines belonging to the same company, that one mine has spent much time, money, and effort in preparing an efficient airway only to have the adjoining mine nullify this effort by closing a door or by using the air course for storing timber, pipe, or other material.

(b) Provision should be made to prevent heated, vitiated return air from entering downcast shafts and contaminating fresh air from the surface. Mines equipped with powerful fans allow as much as 30 to 50 per cent of the air of downcast shafts to come from mine workings, thus decreasing by that amount the possible supply of fresh air from the surface and compelling underground employees to be constantly and unnecessarily in heated, vitiated air.

(c) Mines in the Butte district should endeavor to permit the maximum flow of air in shafts. When cages or skips are not in use they should be lifted free of the shaft; platforms, bulkheads, and other obstructions placed in the pump or pipe compartment for temporary use should be removed as soon as possible, and all unnecessary obstructions to the flow of air should be kept out of all com-

partments. Wherever feasible, all compartments of shafts carrying air should be smooth lined, and particularly the pump compartments.

Falling water should be caught and removed from upcast shafts, but the use of cool sprays in downcast shafts, especially in summer, would facilitate ventilation and cool the heated air coming from the surface.

(*d*) The storage of plank, timbers, and pipe, in drifts and crosscuts used as air courses should be discontinued; the practice of leaving ore cars and locomotives in air courses used as haulage ways should also be discontinued as far as feasible. The usual ore cars have a cross section at least half that of the cross section of the ordinary Butte drift. It is highly desirable and frequently possible to place cars, especially those not in use, on tracks away from air courses.

(*e*) All underground employees should be educated to know the importance of closing doors and keeping air courses free from obstructions. Old-timers, both bosses and miners, particularly need such instruction, as they are too prone to minimize and decry all efforts to make ventilation more efficient. It is practically certain that little or no progress toward improvements in ventilation will be made in many Butte mines until reactionary bosses have been removed.

Ventilation devices should be used efficiently. It is a waste of time, money, and effort to provide canvas pipe for ventilation and then have the end of the canvas pipe so far from the worker that no air reaches him, or to point the end of the pipe so that the issuing air moves from rather than toward him. Moreover, a small fan should not be so placed that it makes air 10° warmer than that available 100 feet distant where a fan can be placed as readily.

(*f*) Miners' consumption is a real menace to workers in hard-rock mines. Its primary cause is the breathing of the microscopically fine particles of siliceous dust which remain suspended in the air almost indefinitely. Next to preventing the formation and dissemination of this dust, the most potent means of rendering it harmless is to remove it from the air. Removal can be effected, at least partly, by water sprays and by ventilating currents of ample volume. Places with still air are especially liable to be dangerous because of fine dust, and the dust-laden air should be removed by the adequate ventilation of all places where men must work.

13. Merely to spend immense sums of money to cause large quantities of air to flow through a few underground drifts and crosscuts will not give efficient ventilation, and most certainly will not produce results justifying the cost. Efficient supervision of ventilation methods and equipment at all times is absolutely essential. Some one must see that the air currents reach the places where the men work.

APPENDIX.

ABSORPTION OF OXYGEN AND PRODUCTION OF CARBON DIOXIDE FROM ATMOSPHERIC AIR BY WOOD.⁵

Below are shown the results of some preliminary experiments having to do with the absorption of oxygen and production of carbon dioxide from atmospheric air by wood. The sawdust used was obtained by sawing dried and seasoned pieces of wood planks; the shavings used in one test were very thin. The bottles used had a capacity of 2½ liters and could be securely closed. Through each stopper a glass tube was placed, provided with a stopcock, to permit withdrawing samples of air for analysis.

Effect of wood in changing the composition of atmospheric air.

Kind of wood and weight in grams.	First analysis, June 27, 1913.	Second analysis, July 15, 1913. ^a	Third analysis, July 31, 1913. ^a	Fourth analysis, Aug. 21, 1913.	Fifth analysis, Sept. 16, 1913.	Sixth analysis, Dec. 9, 1913.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Ash sawdust, CO ₂	.0	.15	3.38	11.6	18.9	20.6
112.5 grams, O ₂	20.8	20.8	17.5	8.6	1.7	.0
Cypress shavings, CO ₂	.0	.15	1.98	4.0	6.0	10
76 grams, O ₂	20.9	20.8	18.75	16.7	14.4	10.1
Hemlock sawdust, CO ₂	.2	.20	7.87	16.6	18.0	17.7
135.5 grams, O ₂	20.8	20.8	12.0	2.0	.7	.3
Oak sawdust, CO ₂	.2	.2	8.27	17.0	19.2	20.2
136 grams, O ₂	20.7	20.8	15.05	3.1	1.2	.4

^a On July 31, after the third analysis, water enough was added to saturate the wood so that it caked.

Discussion of results.—The experiments were started on June 6, 1913. The first analysis of the residual air in the bottles was made on June 27, 1913; it showed no appreciable change in the oxygen or carbon dioxide content of the residual air. The same held true of results obtained on July 15, 1913, or 30 days after starting the experiment. Enough water was then added to each bottle to moisten perceptibly the sawdust and shavings. In 16 days from the time the wood was moistened the residual air in each bottle was sampled and analyzed again. The results showed a marked increase of carbon dioxide and a decrease of oxygen; these changes continued until in the bottles containing sawdust all, or practically all, the oxygen disappeared. In the bottle of cypress shavings the rate of absorption of oxygen was slower. * * *

⁵ Statement of G. A. Burrell, chemist, Bureau of Mines, from a report by Edwin Higgins on "Ventilation in the Iron Mines of the Lake Superior District."

An interesting feature of the results is that the carbon dioxide is only slightly less than the molecular equivalent of the oxygen consumed, a result different from that obtained when oxygen is absorbed by coal at ordinary temperatures, the amount of carbon dioxide produced then being invariably less than the molecular equivalent of the consumed oxygen. This action of coal has been observed in many laboratory experiments by different chemists. Coal may absorb all or almost all the oxygen and yet the residual air may contain only two or three per cent of carbon dioxide.

The loss of oxygen by air during contact with coal may be caused by the slow oxidation of the carbon with formation of a small amount of carbon dioxide; by the oxidation of certain unknown and unsaturated bodies in the coal without formation of carbon dioxide; and possibly by the absorption of oxygen and, presumably, some nitrogen. That carbon dioxide disappears during contact with coal has been determined by experiment.

Bacterial action seemingly is not a factor in the reaction between coal and air. On the other hand, the disappearance of oxygen and formation of carbon dioxide from air in contact with wood is probably due almost entirely to bacterial action. Sometimes small quantities of other gases are formed, methane and hydrogen, for instance. The samples named in the table were not tested for gases other than carbon dioxide and oxygen.

These results show that timber in metal mines where large quantities of it are used, may be responsible for part of the vitiation of mine air, especially in dead ends where the air is stagnant, the wood moist, and much timber is present.

The results, however, are only preliminary and not quantitative, hence give one no idea of the exact part timber plays in the vitiation of the air of metal mines. The fineness of division of the wood is undoubtedly an important factor in the rate of oxygen absorption. Further experiments are needed to determine the rate of the reaction between air and timbers.

In some metal mines pyritic ores, especially iron pyrites, are probably responsible for the disappearance of some of the oxygen. Many of the samples of mine air collected by the Bureau of Mines, however, have shown a quantity of carbon dioxide almost proportional to the vanished oxygen, suggesting that the timber, or some reaction analogous to that between air and wood in laboratory experiments, is responsible for the vitiation of the air.

PUBLICATIONS ON MINE VENTILATION.

A limited supply of the following publications of the Bureau of Mines has been printed and is available for free distribution until the edition is exhausted. Requests for all publications can not be

granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

BULLETIN 57. Safety and efficiency in mine tunneling, by D. W. Brunton and J. A. Davis. 1914. 271 pp., 6 pls., 45 figs.

BULLETIN 75. Rules and regulations for metal mines, by W. R. Ingalls and others. 1915. 296 pp., 1 fig.

BULLETIN 99. Mine ventilation stoppings, with especial reference to coal mines in Illinois, by R. Y. Williams. 1915. 30 pp., 4 pls., 4 figs.

BULLETIN 105. Black damp in mines, by G. A. Burrell, I. W. Robertson, and G. G. Oberfell. 1916. 92 pp.

TECHNICAL PAPER 82. Oxygen mine rescue apparatus and physiological effects on users, by Yandell Henderson and J. W. Paul. 1917. 102 pp., 5 pls., 6 figs.

TECHNICAL PAPER 121. Effects of temperature and pressure on the explosibility of methane-air mixtures, by G. A. Burrell and I. W. Robertson. 1916. 14 pp., 3 figs.

TECHNICAL PAPER 134. Explosibility of gases from mine fires, by G. A. Burrell and G. G. Oberfell. 1916. 31 pp., 1 fig.

TECHNICAL PAPER 154. Suggestions for improved methods of mining coal on Indian lands in Oklahoma, by J. J. Rutledge and Daniel Harrington. 1918. 35 pp., 8 pls., 4 figs.

TECHNICAL PAPER 174. Gasoline mine-motors, by R. H. Kudlich and Edwin Higgins. 1917. 19 pp., 3 figs.

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